TOWARDS A CROP GROWTH, DEVELOPMENT, AND YIELD MODEL FOR *LUPINUS ANGUSTIFOLIUS* L. (NARROW LEAFED LUPIN) IN TASMANIA

by

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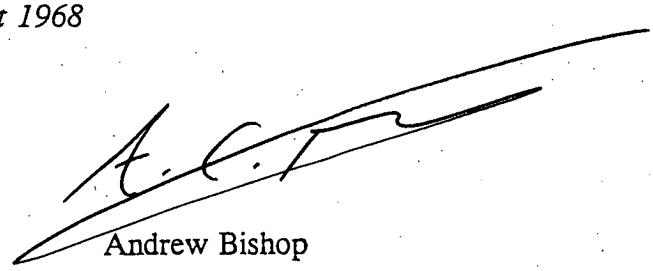

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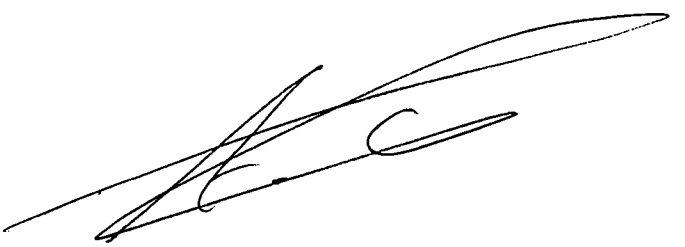

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ABSTRACT

Experiments were conducted between 1988 and 1990 at Elliott, Cressy, and Ross in Tasmania using three cultivars (Yandee, Geebung, and 75A329) of narrow-leafed lupin (*Lupinus angustifolius*). The purpose of these experiments was to examine narrow-leafed lupin growth and development in Tasmania in relation to specific environmental factors. These factors were related to growth and development measurements. It was hoped to use these relationships in a simple crop model suitable for assessing sites for the commercial production of lupins.

Preliminary experiments in 1988 examined the lupin cultivars for agronomic suitability in Tasmania. Increased grain yield was a function of more pods/m^2 rather than increased pods/plant. This suggested that lower yields of the indeterminate line 75A329 could be compensated for by a higher plant density than in the indeterminate cultivars. Lupins responded to higher rainfall and extended growing season at Elliott thus outyielding crops at Cressy and Ross.

Detailed field experiments were conducted in 1989 and 1990 at Elliott and Cressy. Lupin crops developed very slowly in the first 8-10 weeks, and then grew rapidly after flowering was initiated. It appeared floral initiation was a function of higher temperatures and longer days in Yandee and 75A329, with further responses to vernalisation in Geebung.

Plant density significantly affected grain yield. 75A329 showed the largest yield responses to increased plant density. Although increased plant density resulted in increased leaf area, leaf senescence took place earlier in the highest density crops probably due to competitive effects. Optimum density for the indeterminate

cultivars was 40 plants/m^2. It may be higher for determinate cultivars. Low density crops were able to utilise their leaf area for light interception more efficiently than high density crops. In the latter, branches and leaves were pushed more towards vertical rather than horizontal thus less leaf area was presented to intercept light.

The study established that early sowing of lupins in Tasmania allows more time to grow and develop and yield more grain. A direct relationship was established between increased total dry matter and increased grain yield.

The model developed in this study used thermal time as its only external factor to determine L, intercepted radiation (%), and total dry matter (kg/ha) during crop growth. From the predicted figure for total dry matter accumulated by harvest time, an estimate of potential grain yield could be made for that crop.

This study demonstrated the principle of collecting agronomic data and, guided by basic plant physiological principles and mathematical procedures, assembling simple sub-models that when linked can approximate a particular aspect of crop growth.

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CHAPTER ONE

INTRODUCTION

The purpose of the three experiments detailed was to obtain agronomic data on lupin crop growth and development and lupin crop responses to different seasonal weather patterns. The aim of the program was to examine the pattern of growth and development of narrow leafed lupins in Tasmania in relation to environmental factors, in order to assess their suitability for commercial production, if possible via a predictive model.

In Chapter two, I review literature relating to the concept of plant growth and development and the environmental factors that affect both. Much of the literature studies these factors in terms of plant growth modelling. Each of the main operational components of the reviewed models (temperature, radiation, water, plant spacing, soil influences, and dry matter production over time) are reviewed. Where possible, papers relating to the growth analysis of narrow-leafed lupins or similar crops are reviewed in conjunction with the general plant models.

In Chapter three, I detail an experiment that examines the potential for growing narrow-leafed lupins in Tasmania. The aims of this experiment were to collect agronomic data relating to the growth of narrow leafed lupins in Tasmania, and determine if the crop could produce economic grain yields in Tasmania. The data also provided agronomic background on a range of lupin cultivars to be used in modelling experiments. In addition, it provided me with experience in lupin cultivation techniques.

In Chapter four, the effects of the environment and plant densities on lupin crop growth, development, and yield components are quantified at two locations (high and low rainfall) in Tasmania.

Chapter five details a similar experiment to that described in chapter four. The same measurements were taken, thus providing an additional season's data on which lupin crop growth and development was assessed.

In chapter six, an attempt is made to encode possible predictors of lupin grain yield into a spreadsheet format as a very simple model of the growth of the lupin crops examined in this study. The resulting relationships are discussed with regard to their relevance to predictive crop modelling. This chapter also includes some concluding remarks.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter, the concept of plant growth modelling and the potential of applying this concept to modelling the growth of a narrow leafed lupin (*L.angustifolius*) crop is considered. Various crop models developed in recent years are reviewed. The review considers the range of possible model types available from the linear equation to the complex multi-faceted growth simulation model. Each model type is then considered for full or partial application when constructing a growth simulation model for the narrow leafed lupin. Each of the main operational components of the reviewed models (temperature, light, water, plant spacing, soil influences, and production of dry matter over time) are overviewed as potential components of a lupin growth model.

Before proceeding with this review, it is important to define the difference between plant growth and development. Growth refers to the increase in weight, volume, length, or area of some part or all of the plant. Development refers to the timing of critical events in the life cycle of a plant (Ritchie and NeSmith, 1991)

As this review is not intended as a comprehensive coverage of crop physiology, only general physiological concepts are considered. Studies referring to crop plants with potential responses similar to the narrow leafed lupin have been chosen. The literature on the effects of lupin growth response is also reviewed.

2.2. Modelling Crop Growth

The measurement of environmental parameters and how they relate to crop growth has been considered by researchers in recent decades (Katz, 1952; Jones, 1971; McKenzie and Hill, 1989). The development of the computer and the rapid increase in computing power has enabled crop modellers to better understand and test their plant growth simulations. Charles-Edwards (1982) provides a simple summary for a complex subject - 'The acquisition of knowledge of the potential yield of a crop and the understanding of factors affecting that yield are objectives central to almost all agricultural research programs. Statistics has traditionally played an important role in helping to attain them. Mathematics has another, complementary role. Mathematical models enable us to formalise hypotheses about crop performance and about environmental effectors of crop performance. Although dynamic, mathematical simulation models can be resource demanding and often have limited practical value, analytical models may provide a simple and direct approach in elucidating the effectors of potential crop yield. The analyses are subject to practical constraints, but they may provide a useful complementary tool to the traditional methods of crop assessment'.

2.2.1. Major crop models

This section briefly covers the major crop model types that have been developed.

2.2.1.1. Reduced factor models

(a) Climate driven:

Climate driven models are favoured due to the ability to extend the model to a variety of locations provided the necessary weather data is available. Temperature, photoperiod, rainfall, and evaporation are usually selected either as single or multiple predictors in climate-driven models that usually predict yield (Robertson, 1983).

(b) Soil water balance:

Water-balance models have been developed for cereals (Cordery and Graham, 1989; Ragab *et al.*, 1990 a, b). Such models usually incorporate some form of soil water profile against time. This balancing is based on rainfall and potential evapotranspiration. Relationships between soil water balance, crop yield, and accumulated plant biomass over time will provide simulation of plant growth given appropriate inputs (Charles-Edwards, 1982).

In its simplest form, a soil-water balance model can be calculated from the soil water holding capacity, daily rainfall, and pan A evaporation (McAlpine, 1970). However, there are more sophisticated methods of soil water measurement such as the neutron probe, and time-domain reflectometry (Grantz *et al.*, 1990) which are more accurate, but expensive.

(c) Density:

This model type varies in its complexity but the main drive of the model is plant density. Berry (1967) produced a model for regularly spaced vegetables that took plant arrangement into account when predicting crop yield. Hughes (1987) further developed this approach by introducing a cause of variable density in crops (plant pest injury)

and based yield predictions on plant density and pattern of plant injury.

(d) Other reduced factor models:

Other models use soil mineral relationships as the main factors driving the model. Preliminary models for predicting corn yield response to nitrogen fertiliser (Cerrato and Blackmer, 1990) showed significant correlations between rate of fertiliser application and yield. Cerrato's work further showed the importance of selecting the most accurate modelling technique, particularly when the driving component of the model (nitrogen application) is variable and can be controlled.

Advances in plant physiology and the increase in analytical abilities have seen simple reduced factor models developed into more complex structures based on several diverse criteria. Several workers (Baier and Robertson, 1965; Haun, 1974; Weir *et al.*, 1984) have chosen a number of climate and environment effectors to use in predicting not only plant yields but important development stages as well. Haun (1974) in confining his wheat yield model to temperature and rainfall data, developed a two equation system (crop growth and grain yield) to ultimately predict wheat yield. The strength of his model when tested on non-experimental data demonstrated the usefulness of this approach to crop modelling.

Haun (1974) emphasised the need for input data to be readily available for models that are to be used in practical on-farm situations. This is a constraint that limits input variables. Research by Baier and Robertson (1965) has enabled factors such as evapotranspiration to be obtained from readily available climate data. This increased the understanding of potential crop response when using a model driven by weather observations.

2.2.1.2. Multiple predictor models

A progression in complexity amongst multiple-predictor models resulted in improvements in forecast accuracy of models. Williams *et al.* (1975) incorporated soil physical properties and geographical characteristics into elementary rainfall-evapotranspiration models thereby improving their accuracy.

The primary purpose of most crop models has been to forecast yield. Developments in crop modelling have led to many models simulating plant growth and forecasting the occurrence of stages in crop ontogeny. The importance of predicting developmental stages such as flowering in relation to climate occurences, such as frosts, plays a major role in assessing regional crop prospects and geographic suitability. An example of this type of model (FLOWER) has been developed for wheat in Western Australia (Elliott and Loss, 1989; Loss *et al.*, 1990). FLOWER is a computerised multiple-predictor model developed to predict flowering dates for several wheat and barley varieties.

Advances in computing power and computer applications have led to the combination of multiple-predictor models into near-complete computerised model systems. These programs are being developed and marketed as crop management decision-support tools capable of plant growth simulation, yield prediction, and provision of management strategy advice in response to specific data input. SIRAGCROP (Stapper and Murray, 1986) is a system dealing with irrigated wheat. It includes such diverse inputs as plant variety, irrigation, fertiliser application, and time of sowing. Ralph (1990) details the cotton management package, SIRATAC. It is a good example of a complete plant model system driven by agronomic data, insect counts, fruit counts, and weather data. ALFALFA (Denison

and Loomis, 1987) is an integrative physiological model of alfalfa growth and development, and is comprised of a suite of complete plant models. Written in structured Fortran, ALFALFA is based on integrative plant physiology and morphology. It takes into account carbon dioxide assimilation in the crop canopy based on canopy-photosynthetic routines. Its main driving component is daily weather data from standard meteorological reports.

2.2.2. Modelling of the narrow leafed lupin

A review of the crop model literature indicates that much modelling work has been done on cereals due to their economic importance in agriculture, but crop growth modelling of narrow leafed lupins has been minimal. Some exploratory work was carried out by Greenwood *et al.* (1975). This took the form of a study of time course development of a lupin crop that aimed at gaining an insight into which factors influenced yield.

2.3. Effector Variables

2.3.1. Time of sowing

Workers often study time of sowing as an effector on yield. Time of sowing is a combination of the effect of water, temperature, and both daylength and radiation on plant growth. Time of sowing experiments on cereals (Green *et al.*, 1985), vegetables (Chung, 1985; Hardwick *et al.*, 1978; Husain *et al.*, 1988), and oil seed crops (Mendham *et al.*, 1981; Thurling, 1974) are extensive and effective in

documenting the major effect environment has on economic crop yields.

Time of sowing experiments for lupins have been the subject of extensive study. In New Zealand, Withers (1975) showed a linear reduction in yield with sowings from April through to October. He further highlighted the importance of lateral branch number, subsequent inflorescences, and developed pods when considering grain yield. It was evident in that study that environmental conditions such as moisture stress and longer days, combined in later sowings to limit lateral branching and pod filling resulting in decreased yields. Also in New Zealand, Goulden (1976) conclusively demonstrated this with his experiments highlighting the importance of correct sowing date for narrow leafed lupin. Garside (1979) in Tasmania reported similar findings to Withers (1975). Studies by Farrington (1974) in Western Australia on sowing times highlighted the major contribution of moisture stress to reduced yields in late plantings. As dry weather usually commences in October in Western Australia, planting time for lupins is critical. Farrington's experiments with early flowering Unicrop and late flowering Uniharvest lupins showed that a four week delay in planting from May to June reduced yield by more than 50%. Yield reductions were greater for the late flowering Uniharvest. Farrington concluded that lupin grain yields were seriously affected by shortened growing seasons.

Perry and Poole (1975) confirmed the importance of time of sowing, particularly in the Western Australian environment. Their experimental results suggested that the lupin plant retains the capacity to fill pods on ever increasing numbers of laterals almost to the end of the season. A long favourable season is critical for high yield. Perry (1975), in more detailed investigations on the effects of

planting time on a variety of yield components of the plants, detected a slight decline in mean seed weight with later plantings. Dry matter production also declined with later plantings due to a shortened season.

2.3.2. Temperature

Air temperature is a significant environmental effector of plant growth and development from germination through to maturity (Robertson, 1983).

Some cultivars of lupins released during the 1970's, such as Uniharvest, had a vernalisation requirement and are classed as winter types (Nelson and Delane, 1990). Removal of the vernalization requirement in most new cultivars had a major impact on the industry. Nelson and Delane (1990) report that optimum development temperatures are warm (20-25^{o}C day, 10-15^{o}C night) so lupin is now regarded as a crop without the need for vernalising temperatures. A breeding program in Western Australia has incorporated the dominant form of the Ku gene (which removes the vernalisation response) into several lupin cultivars such as Unicrop (Gladstones, 1982) and the recessive efl (which gives a small vernalisation response) into mid-season cultivars such as Wandoo.

Soil temperature has an influence on seed germination. Workers have detected correlations between levels of seedling emergence and seed bed temperature. The pea (*Pisum sativum*) shows little growth and poor emergence below 5^{0}C (Katz, 1952). Nelson and Delane (1990) reported that lupins respond dramatically to warm soil temperatures in May in Western Australia. Cardwell (1984) states that the seeds of each species and cultivar have a minimum, optimum, and maximum temperature for germination.

The minimum temperature may be near freezing and the absolute maximum approaches 50^0C, at which some plant proteins become denatured if they are hydrated.

2.3.2.1 Expression of temperature in modelling

The period from plant emergence to maturity is the one that modellers use as a basis for a temperature component in the plant model. The concept of thermal time is generally used with heat units, often expressed as degree days. A degree day is represented by a mean temperature one degree above a threshold temperature for a period of one day. The threshold is dependent upon the particular plant or crop and stage of development being considered. More recent developments with heat units have also included an upper threshold temperature (Ritchie and NeSmith, 1991). The use of heat units in predicting plant maturity dates has been used for many commercial crops. Some common examples are peas (Katz, 1952), beans (Jones, 1971; Kish and Ogle, 1980), maize (Gilmore and Rogers, 1958; Gross *et al.*, 1972; Phipps *et al.*, 1975; Bunting, 1976) and cereals (Fischer, 1985). Apart from the determination of crop maturity, the concept of heat unit accumulation has been applied by workers to predicting a variety of important physiological stages through development (Scully and Waines, 1988).

There have been no detailed attempts to relate thermal time to particular development stages of lupins although such applications have been made with other grain legume crops such as soybean and lentils (McKenzie and Hill, 1989).

Graham (1979) showed that temperature significantly affected nitrogen fixation of beans. When he lowered temperature of experimental plants, the fixation process decreased. The delay in

fixation with reduced temperature led to visible plant nitrogen deficiency four weeks after planting. As beans are sub-tropical, such response may occur at much lower temperatures in lupins as they are temperate species.

Total dry matter accumulated over ontogeny may be directly influenced by temperature. Aniszewski (1988) looked at dry matter formation in cultivars of narrow-leafed lupins in Finland. He was able to relate temperature and other climate factors to quantity and formation of dry matter. The effect of temperature on the degree of leaf expansion has implications that affect other growth-essential processes such as light interception. Low temperatures in the sub-tropical grain sorghum reduces dry matter production because of lower leaf area thus resulting in poor levels of radiation use efficiency (Hammer *et al.*, 1989 a, b). Austin and MacLean (1972) noted that temperature increases resulted in higher levels of dry matter production in French bean (*Phaseolus vulgaris*) crops. A temperature regime of 12.5^{o}C (night) and 20^{o}C (day) increased photosynthesis in the bean plants compared to lower temperature regimes, resulting in the production of more assimilate. The relationship between temperature and dry matter production is parabolic. Above a certain threshold, high temperatures may destroy certain plant hormones, thus reducing plant growth (Robertson, 1983).

Nelson and Delane (1990) state that the internode length of the lupin plant is affected by both temperature and light. Studies by Downes and Gladstones (1984b) have shown that the optimum flowering temperature for lupins is between 16-21^{o}C. Flower development was rapid at 16^{o}C and showed little increase between 21-28^{o}C. The experiments of Downes and Gladstones (1984a, b, c) further showed temperature stress in lupin plants resulted in

substantial yield reduction. They report that the decrease in yield resulted from premature abortion of the flowers.

Temperature interactions with other environmental effectors are common, and temperature-photoperiod responses have been studied for many crop types. Angus *et al.* (1981) provide a good example of a temperature-photoperiod linked relationship for wheat. Ellis *et al.* (1988a, b) highlighted a variety of flowering responses to temperature, photoperiod, and photothermal time for a range of faba bean cultivars. Rahman and Gladstones (1974) studied vernalization triggers, photoperiod triggers, and combined triggers for flowering in several lupin species.

2.3.3. Radiation

Monteith (1979) showed that the rate of crop growth is proportional to the rate of photosynthesis and depends upon the amount of radiant energy that is intercepted by the foliage. The production of dry matter in crops has been related directly to photosynthesis via the amount of light intercepted by the plant (Allen and Scott, 1980). Gallagher and Biscoe (1978) related dry matter production directly to photosynthesis with experiments on cereal plants and calculated the amount of dry matter produced per megajoule of photosynthetically active radiation. In addition they were able to show that a stressed crop resulted in decreased growth efficiency and lower photosynthetic efficiency.

Black and Watson (1960) suggest agriculture is a system of 'exploiting photosynthesis'. Some 85-90% of the dry matter of plants is carbonaceous material derived from photosynthesis (Milthorpe and Moorby, 1974).

Only about half the shortwave radiation reaching the plant surface can be used in the photosynthetic process. Studies of solar radiation and its spectral composition, and solar elevation (Szeicz, 1974) show that photosynthetically useful radiation reaching plants is restricted to a wavelength range of 400 to 700 nm (Charles-Edwards, 1982). Environmental differences, such as air quality, and the time of year all affect the amount of light eventually made available to the plant for photosynthesis and evaporation.

2.3.3.1 Interception of light by plants

Plant leaves are the major light intercepting structure on the plant. Leaf characteristics form an important focal point of study into light influence on crop growth. Leaf area index (L) is a ratio of total leaf area per unit area of ground. Generally, increases in L result in increased light interception by the plant and reduced light penetration to lower levels of the leaf canopy (Wilfong *et al.*, 1967). Firman and Allen (1988) detailed the importance of such a relationship and the importance of leaf angle and arrangement to maximise efficient crop growth and plant yield. These relationships are applicable to most crop situations (Ramos and Recalde, 1985).

Estimates of maximum leaf area indices and the relative percentage of light intercepted differ for different crops. Greenwood *et al.* (1975) in Western Australia found that autumn sown lupins (cv. Unicrop) took ten weeks to attain a L of 1 and a further nine weeks to reach a maximum L of 3.75. As plant densities were high (33-44 plants/m^2, the time it took to reach an L of 1 was due to slow rate of leaf expansion (compared with soybeans for example) rather than a low plant population. Greenwood et al suggested that temperature and limiting nitrogen levels contributed to the slow growth rate.

However, at the maximum L of 3.75, only 33% of light reached pods situated on the main axis beneath the leaf canopy.

The plant's ability to intercept light, particularly in a crop situation, is highly dependent on plant arrangement and density. Zaffaroni and Schneiter (1989) found that the actual efficiency at which a sunflower crop intercepts light is influenced by the row arrangement chosen in sowing. Tetio-Kagho and Gardener (1988) concluded that increasing the plant density of maize increases L and vegetative dry matter yield and significantly alters the distribution of light through the canopy. This has implications for efficient use of leaf surface area in high density crops.

2.3.3.2 Interaction of radiation and other factors

Environmental effectors, such as temperature, interact with leaf area to affect light interception and photosynthetic efficiency. Littleton *et al.* (1979a, b) showed that like most crops, cowpea responds to increased temperature with faster development of leaf area, implying a direct temperature influence on light interception ability of the plant.

Studies by Greenwood *et al.* (1975) provide a guide to the importance of light in the growth of the narrow leafed lupin. The length of time it takes for a crop to develop the optimum L to intercept maximum levels of light indicates the importance of plant spacing. The time factor would be combined with natural leaf abscission (influenced by environment stress). This suggests that light interception as influenced by environment is an important growth factor in modelling.

In addition to radiation effects on plant growth, Rahman and Gladstones (1972, 1974) found that an increased photoperiod

accelerated flowering in narrow leafed lupin. Although the response was not strong, Gladstones and Hill (1969) had previously suggested that vernalization requirements were masking the full extent of photoperiod response. If this is the case, there may be more obvious photoperiod responses in the modern early flowering cultivars.

2.3.4. Water

Biddiscombe (1975) found moisture stress during flowering in lupin crops reduced grain yield. There was a 15% increase in flower drop and a 47% decrease in seed yield of the lupin. Biddiscombe attributed the reduced plant size with subsequent reduced pod number as the main contributor to the yield decrease. The increase in flower drop was a factor but serious losses were noted even under favourable moisture conditions. When the stress occurred during the post-flowering period, seed yield decreased by 20%.

Zaffaroni (1989) stated that economic crop production is the conversion of three natural resources (light, water, and nutrients) into usable products by the plant. When considering water availability for plant growth, temperature and water effects are not independent in real production situations (Eastin and Sullivan., 1984)

The availability of soil water to the crop (water balance) and its efficient use by that crop (water use efficiency) contributes directly to the economic crop yield. Water balance models are an account of the water input (rain and irrigation), the soil water storage, and the water lost by runoff, deep drainage, soil evaporation, and evapotranspiration (McAlpine, 1970). Soil water availability and use are influenced by hydraulic properties of soil, plant root concentration, and weather conditions (Milthorpe and Moorby, 1974).

Waterlogging harms lupin plants. Broue *et al.* (1976) found that a loss of root hairs and finer roots was an invariable symptom of waterlogging in lupins at all stages of development as was the plant's greater susceptibility to root rot diseases. On well drained soils, however, yield of lupins can be greatly improved by irrigation during flowering and pod set (Stoker, 1975). The increased yield results from increased numbers of lateral branches bearing pods, and increased numbers of pods. The level of response is influenced by the frequency of rainfall.

2.3.5. Plant density

Optimum plant spacing enables a plant population to maximise available resources and produce maximum yield. Particularly in a crop situation, plant population must be considered as an effector of plant growth and hence yields.

Density studies have been made on a large range of economically significant crops including broccoli (Chung, 1982), durum wheat (Ottoman, 1990), and grain legumes (Chung and Goulden, 1970; Lucas and Milbourn, 1976; Yunusa, 1989; Pilbeam *et al.*, 1990). These studies indicate optimum plant densities under particular conditions for each crop.

The yield-density response can also be characterised by general mathematical equations (Gillis and Ratkowsky, 1978). The Holliday equation (Holliday, 1960) is a well established relationship:

$$1/W = \alpha + \beta p + \gamma p^2$$

W = Weight/plant, p = plant density, α, β, and γ are model parameters

Two distinct relationships exist for yield and density that can be represented by this equation. If the yield referred to is vegetative or total dry matter, then the relationship between yield and

increasing density is usually asymptotic and $\gamma = 0$. If the economic yield is the reproductive component, the relationship is often parabolic and $\gamma > 0$ (Frappell,1979; Nicholls, 1990).

The basis for density effects on crop growth is competition. Frappell (1979) defines competition as a 'process in which two or more organisms in close proximity interact for a portion of an environmental factor which is not available in a supply sufficient to meet their combined demands'. In the density trials referred to above, competition is the focus of each study. The competition-density effect is expanded upon in great detail by Shinozaki and Kira (1956). Consideration also needs to be given to interspecific competition, usually being with weeds (Hewson *et al.*, 1973).

Workers have recognised the importance of plant density to maximise lupin grain production since the release of the first crop type cultivars in the 1970`s. Withers and colleagues (1974, 1975) conducted density trials with Unicrop lupins in Western Australia. Initial experiments were frustrated by poor environmental conditions that resulted in only a narrow range of plant densities being used. Further experiments provided more useful results with significant yield increases resulting from increased population. Goulden (1976) conducted density trials in New Zealand based on sowing rate. His trials suggested sowing rates of between 168 and 202 kg/ha of Uniharvest lupins were optimal. The study lacked density counts and is difficult to quantify when considering the relationships between plant number and final grain yield. Clapham (1989) showed inversely proportional relationships existed between plant density and pods, seed/pod, fruiting sites, and lateral branch number.

French (1988) studied the yield/density relationship for the narrow leafed lupin in Western Australia. He was able to correlate

data from fourteen sowing rate trials. Using the results of fitted curves, 40 plants/m^2 were recommended as the plant density to maximise yield under Western Australian conditions.

Within any study of plant density effects on plant yield, consideration should also be given to plant arrangement. The spatial distribution of plants within a population greatly influences a plant's ability to efficiently intercept solar radiation and maximise photosynthetic efficiency (Frappell, 1979).

Lupin plants can be of a determinate or indeterminate type, so branch structural differences are likely to result in density effects that need to be accounted for. High densities will result in minimal branching of indeterminate cultivars, and possibly reduced yield. Hence indeterminate cultivars are likely to have a lower optimum density than determinate cultivars. Donald and Hamblin (1983) highlight the advantages of determinate growth in annual seed crops (such as lupins). Higher target densities can be selected as extensive branching does not occur. This allows a closer spacing of plants minimising weed competition early in the growth period. In addition the higher plant populations may well have yield advantages. These may be offset by higher seed costs.

2.3.6. Soil

The structure of the soil, its water holding potential, and seed-soil surface contact determines the rate of moisture uptake by the plant seed in the soil. This directly affects seed germination, emergence level, plant density, and finally yield (Cardwell, 1984).

2.3.6.1. Soil nutrients

In certain cases, the deficiency of available minerals result in stunted plant growth and reduced yield. White and Robson (1989 a, b) determined that the poor growth and chlorosis suffered by lupins when grown on fine textured alkaline soils was related to iron deficiency. They found lupin plant growth was closely related to the concentration of iron within young leaves. When the soil was limed or watered above field capacity, the iron concentration of shoots was reduced, chlorosis was induced, and growth rate slowed. White and Robson (1989 a) concluded that lime chlorosis disorder in lupins was primarily caused by inability of the plant to obtain sufficient iron in calcareous soils. This indicates that the narrow leafed lupin is specifically adapted to acid soils.

2.3.6.2. Soil pore size

Pore size between soil particles not only affects soil hydraulic conductivity, it also influences plant root growth and development (Cardwell 1984). Lupins possess an adaptive trait that enables them to grow in compacted soil. Atwell (1988) studied how lupin roots responded to, and coped with, compacted soil. The physiological response is a radial swelling of the main tap root. The swelling originates from cortex expansion while the stele remains constant in diameter.

2.3.6.3. Soil characteristics and lupin growth

Fine textured, alkaline, or poorly drained soils affect lupin plant growth. White and Robson (1989c) showed that poor soil structure,

high pH, and mineral deficiencies work together to produce poor lupin growth. White and Robson (1989d) highlighted the weakness of emerging lupin plants following formation of a soil crust. They found the lupin plant is weak and vulnerable in its early stages. The soil crust severely reduced plant emergence. When the seed was sown deeper, the problem became worse.

The growth and development of narrow leafed lupins have been shown to be affected by factors such as temperature, plant density, soil moisture and physical structure. This literature review has detailed these factors and their effect on plant growth and development. The use of mathematical models to assess the level of crop response due to these factors has also been examined.

The following experimental program was designed to obtain agronomic data on narrow leafed lupin growth in Tasmania and determine the effects of several factors detailed in this literature review on the commercial viability of lupin production in Tasmania. In addition, an attempt was made to develop a simple mathematical crop growth model to test the effect of specific factors, such as temperature, on lupin growth and lupin grain yield in Tasmania.

CHAPTER THREE

A PRELIMINARY STUDY OF THREE LUPIN CULTIVARS IN TASMANIA

3.1. Introduction

The area planted to narrow leafed lupins in Tasmania increased from 80 hectares in 1983 to 1300 hectares in 1989 (Australian Bureau of Statistics, 1989). However, farmer concerns about the low yield of the lupin crop have limited lupins to land of lower productive potential. Based on the established Tasmanian average of less than one tonne/hectare (ABS, 1989), it would be uneconomic to grow lupins in many areas of the state (Appendix F). This experiment was designed to determine if lupins could be grown economically in Tasmania, particularly when compared to other established crops such as poppies and cereals.

3.2. Aim

(i) To collect agronomic data relating to the growth of the narrow leafed lupin in Tasmania.

(ii) To assess the cropping potential of a range of narrow leafed lupin cultivars (Plates 2.1 & 2.2, Table 2.1).

Plate 3.1. The three narrow leafed lupin cultivars: Geebung (left), 75A329 (centre), and Yandee (right) in the experiment at Elliott. The determinate branch structure of 75A329 is highlighted by the primary stem pods that are close to ripening.

Plate 3.2. Determinate branched cultivar 75A329 (left) and indeterminate branched cultivar Yandee (right).

iii) To become familiar with the cultivation of lupins in preparation for their inclusion in agronomic and crop modelling experiments.

3.3. MATERIALS & METHODS

The experiment was conducted over a two year period (1988 & 1989) at Elliott and Ross using 24 lupin cultivars which had shown potential in a previous exploratory experiment (Talay, unpublished results). The data from only three cultivars are detailed in this chapter. These three cultivars were selected for further experimentation in subsequent years and are related directly to this thesis. The three cultivars were chosen to represent the main genotype characteristics (Table 3.1) of the narrow leafed lupin.

Table 3.1 Characteristics of the three cultivars examined in this chapter.

Cultivar	Yandee	Geebung	75A329
Flower	Early	Late	Early
Vernalise	No	Yes	No
Year of Release	1980	1986	no release
Maturity	Early	Mid	Late
Branch type	ID	ID	D
Height	Medium	Medium	Tall
Lodging	S	VT	unknown
Shattering	MS	T	unknown

D = Determinate branching ID = Indeterminate branching

MS = Moderately Susceptible; S = Susceptible

T = Tolerant; VT = Very Tolerant.

3.3.1. Location of Experimental Sites-

The experiment was located at Elliott, Ross, and Cressy.which differed in elevation, annual rainfall, and soil type (Table 3.2, Appendix G).

Table 3.2. Experimental site descriptions. (See Appendix A for detail). Elevation is measured as metres above sea level.

Site	Elliott	Ross	Cressy
Year	1988	1988	1989
Latitude	41°0'S	42°2'S	41°41'S
Elevation	122 m	220 m	150 m
Rainfall (annual)	1200 mm	408 mm	645 mm
Soil types	krasnozem	sand/loam	panshangar sand

3.3.2. Experimental Design

Yandee, Geebung, 75A329, and ten other cultivars (not reported in this thesis) were planted in 10m x 1.5m plots replicated three times in a randomised complete block design. The analysis presented in this experiment is based on only the three cultivars, Yandee, Geebung, and 75A329. Only these three varieties are reported on due to their direct relevance to this study ie. representative of the range of characteristics to be included in the thesis.

3.3.3. Experimental details

The experiment consisted of autumn (Ross and Cressy) and spring (Elliott) sowings of lupins. Sowing dates and rates were based on previous work (Talay, unpublished results) suggesting these to be approximately suitable for Tasmanian conditions. Details of the sowings at each site are in Table 3.3.

3.3.4. Weather details

Rainfall, evaporation (class A pan), and temperature data were collected from meteorological stations at Elliott and Cressy (Fig 3.1). These stations were situated within 500 metres of the experiment sites.

Table 3.3. Summary of procedure used in establishing the experiment at three sites.

Site	Elliott	Ross*	Cressy#
Year	1988	1988	1989
Sown	Sep 15	May 26	Jun 1
Seed rate (kg/ha)	100	100	100
Inoculum	Group G	Group G	Group G
Fertiliser: type (N:P:K)	3:6:8	nil	3:6:8
rate (kg/ha)	100	nil	100
Herbicide: type	Metribuzin used at each site		
rate (g ai/ha)	140	250	250

* = no fertiliser applied due to oversight.

\# = Yandee and Geebung only (Insufficient seed of 75A329).

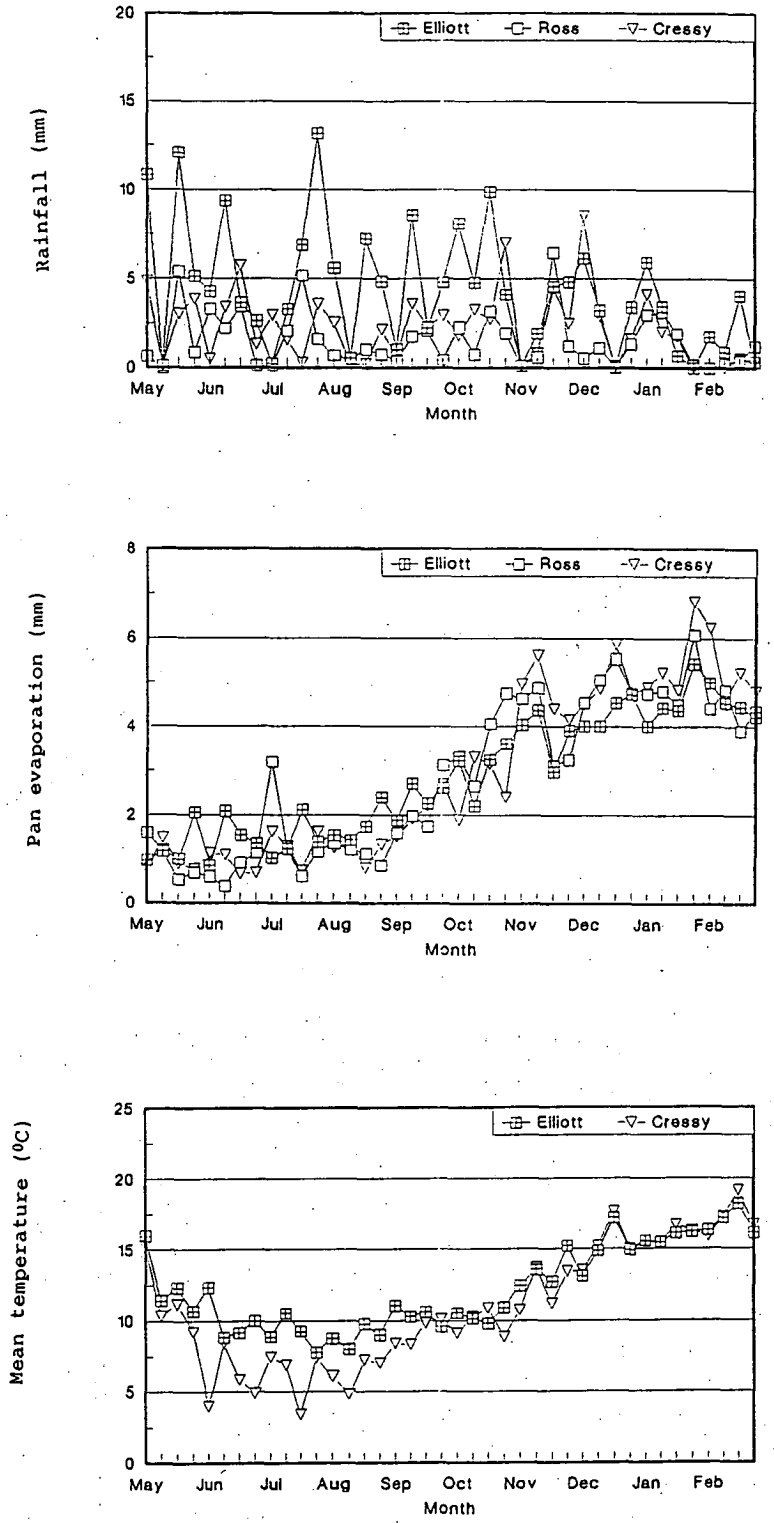

Fig 3.1. Mean weekly weather data measured at each experimental site for the relevant seasons.

For the Ross site, rainfall and evaporation (class A pan) data were collected from a meteorological station at Oatlands approximately 50 km south of Ross (Fig 3.1).

3.3.5. Data collection

During crop growth

(i) Plant density four weeks after emergence.

(ii) Time of flowering (observations made every seven days).

At crop maturity

Yield components (below) were assessed on ten plants per plot at Elliott and Ross as representative of high and low rainfall regions.

(i) 100 seed weight

(ii Seeds/pod

(iii) Pods/plant

(iv) Harvested grain yield

At Cressy only harvested grain yield was recorded as resources were not available to partition sample plants from both sites before the plants deteriorated..

3.3.6. Machine harvest

The experiment was machine harvested with a Claas(R) header (Elliott) and a Wintersteiger(R) Nurserymaster header (Ross and Cressy).

3.4. RESULTS AND DISCUSSION

3.4.1. Plant Population

Plant density counts indicated a significantly ($p<0.05$) higher population of 75A329 than Yandee at the Elliott site (Fig 3.2). The poor emergence of Yandee possibly was due to old seed. There were also more 75A329 plants than Geebung plants although the difference was not statistically significant. This density difference probably resulted from the sowing rate of 100 kg/ha used for all cultivars despite differences in seed size (Fig 3.3c). The seeds of 75A329 were smaller than Yandee or Geebung resulting in more plants sown per area.

Plant density counts at Ross showed differences although without statistical significance. The seed source of 75A329 used at Ross was different to that used at Elliott and was older. Some germination problems were encountered. This probably explains the lower density of 75A329 at Ross compared with Elliott. The seed sources for Yandee and Geebung were the same for all sites. At Cressy, populations did not differ significantly.

3.4.2. Time of flowering

As experiments were observed every seven days, the time for each phenological period was interpolated. The approximate time for each cultivar at each site to reach flowering, its period of flowering, and total time to mature are compared in Table 3.4. The time taken for Yandee and Geebung to flower was not significantly different at Elliott

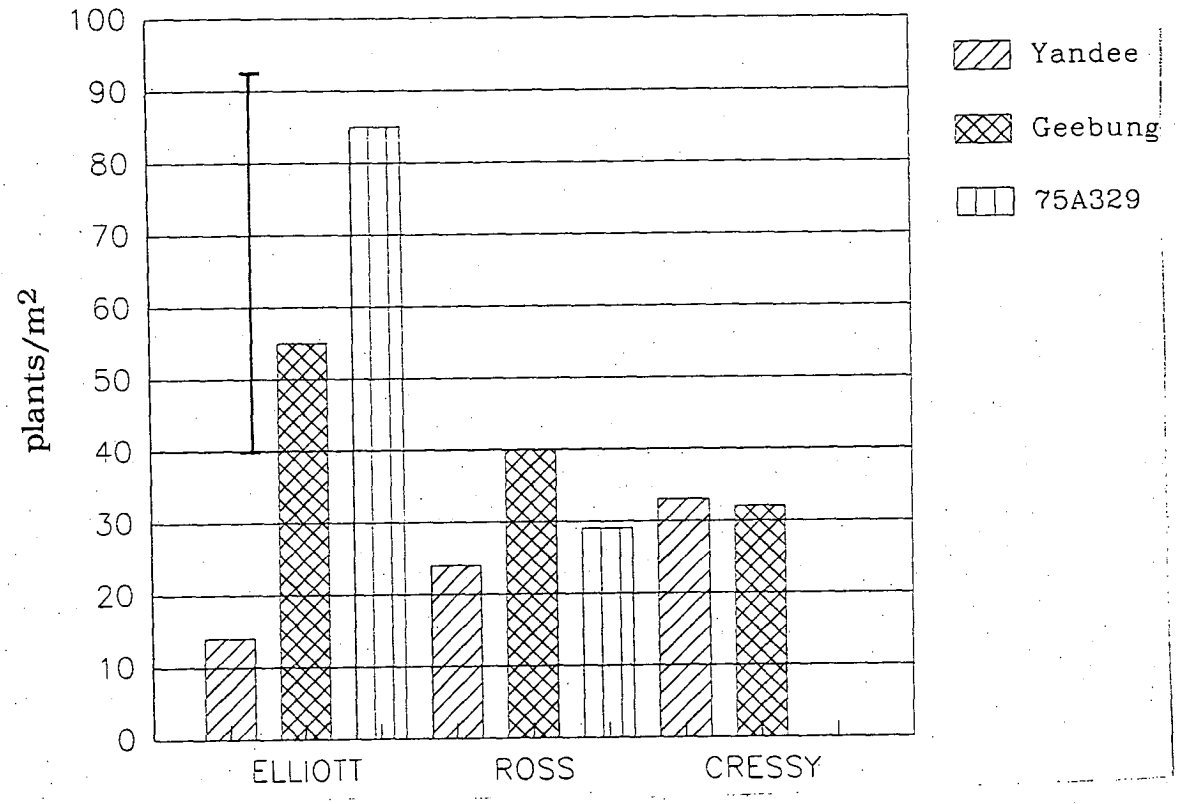

Fig 3.2. Cultivar plant densities (plants/m^2) at each site, counted four weeks after emergence.
Bar indicates $LSD_{0.05}$ for Elliott. No significant differences at Ross or Cressy

Table 3.4. Phenology of lupin cultivars at each site.

Site	Cultivar	Sown	S-F(d)	F(d)	S-M(d)
Elliott	Yandee	15 Sep	78	18	131
Elliott	Geebung	15 Sep	79	21	152
Elliott	75A329	15 Sep	73	29	139
$LSD_{0.05}$			1.99	1.99	1.99
Ross	Yandee	26 May	138	21	220
Ross	Geebung	26 May	139	21	219
Ross	75A329	26 May	138	29	232
$LSD_{0.05}$			n.s.	1.99	1.99
Cressy	Yandee	1 Jun	131	21	231
Cressy	Geebung	1 Jun	126	21	231
$LSD_{0.05}$			2.45	n.s.	n.s.

S-F(d) = Period from sowing to commencement of flowering in days.

F(d) = Period of flowering (1st mainstem flowers to last secondary flowers) in days.

S-M(d) = Period from sowing to crop maturity in days.

and Ross, although at Cressy, Yandee took significantly longer to flower. This was not explained by any of the measured variables.

The determinate cultivar 75A329 differed significantly from the indeterminate cultivars in most of the development stages. In contrast to the findings of Delane *et al.* (1986) in Western Australia, 75A329 had a significantly longer flowering period than Yandee or Geebung. Perhaps this contradiction is explained by the lower temperature received at the Tasmanian sites thus extending the

period of flowering of the mainstem and upper branches of the determinate 75A329. 75A329 is determinate in the sense of restricted branching, but can continue to flower on the mainstem and upper branches if conditions are suitable.

75A329 also took longer to mature in the autumn sowing at Ross compared with Yandee and Geebung. Despite genotype contrasts, the early flowering Yandee and the late-flowering Geebung were not significantly different in their development when autumn sown at the low rainfall sites. When spring sown at Elliott, Yandee developed after flowering and matured more rapidly than Geebung. This was consistent with its early genotypic characteristics (Pate, *et al.*, 1985). The 'late' cultivar, Geebung probably was fully vernalised from the autumn sowing and then awaited warmer weather and longer days before flowering at the same time as the 'early' cultivar, Yandee.

3.4.3. Dry matter partitioning

Yandee set significantly ($p<0.05$) more pods/plant than Geebung (Fig 3.3a) at Elliott. Numbers of seed per pod (Fig 3.3b) did not differ significantly, but Yandee produced the heaviest seed (Fig 3.3c). Despite the apparent yield advantages per plant for Yandee, its harvested grain yield was significantly lower than Geebung at each site (Fig 3.3d). While no doubt partly due to lower density at Elliott, and possibly Ross, at Cressy yields of Yandee were still lower whereas density was greater than for Geebung.

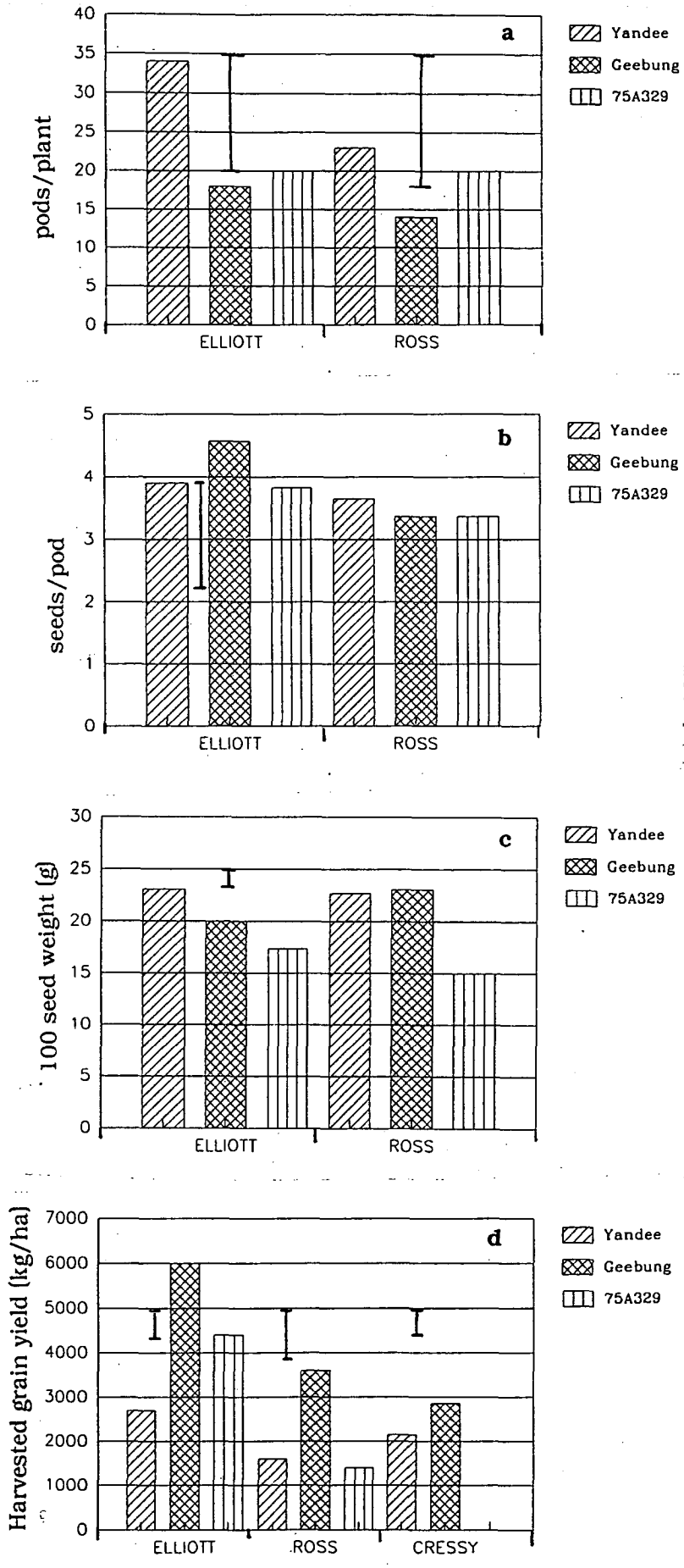

Fig 3.3. Yield components for Yandee, Geebung, and 75A329 at Elliott and Ross. Bars indicate $LSD_{0.05}$.

Yandee also set more pods/plant at Elliott than 75A329 (Fig 3.3a) due to its significantly lower density at Elliott, but less at Ross where there were no significant differences between plant density, pods/plant, or harvested grain yield for Yandee and 75A329.

All cultivars, except Yandee, yielded more grain at the later planted Elliott site than at Ross and Cressy (Fig 3.3d). At first, this appears to contradict the findings of previous workers (Withers *et al.*, 1974; Goulden, 1976; Garside, 1979). However, higher rainfall at Elliott combined with an irrigation of 50mm during flowering effectively extended the season. The higher yields of Geebung at Elliott under these conditions confirm the suggestion of Perry and Poole (1975) that the lupin plant retains the capacity to fill pods on ever-increasing numbers of laterals until the season ends. The determinate 75A329 yields were probably a function of its very high density at Elliott compared with Ross. The higher rainfall and additional irrigation at Elliott created an extended season.

3.5. Conclusions

Geebung was the highest yielding cultivar because of bigger seed compared with 75A329, greater number of seeds/pod (Elliott only) and higher plant density (Elliott) At Cressy, both Yandee and Geebung yielded similar amounts of grain and were evenly matched in their plant densities. The spring planting with irrigation gave the highest yields. Yields of well above the State's average of one tonne/hectare are clearly possible with either autumn planting in the low rainfall midlands of Tasmania, or production under irrigation on well drained soils, whether autumn or spring sown. Based on the economic scenarios in Appendix E, yields in excess of one

tonne/hectare would be required to make a profit. The yields achieved in this experiment indicated it is possible to produce economically viable lupin crops.

The data collected in this experiment suggested broad differences in development pattern between the indeterminate cultivars (Yandee and Geebung) and the determinate cultivar (75A329). The experiment provided a basic understanding of lupin cultivation at high and low rainfall sites. This familiarity with the narrow leafed lupin plant's agronomy will assist in a more detailed study of lupin growth in Tasmania. In this experiment, the differences in plant establishment and final density between cultivars and sites made interpretation of the results difficult; plant density needs to be examined more closely in further experiments. These experiments will also attempt to detail how the lupin plant responds to its environment to provide a basis for a model of crop growth and development.

CHAPTER FOUR

THE EFFECT OF PLANT DENSITY AND ENVIRONMENTAL FACTORS ON LUPIN CROP GROWTH AND DEVELOPMENT AT TWO SITES IN TASMANIA (1989)

4.1. Introduction

Monteith (1979) indicated that the concept of growth analysis when properly applied, and based on interception and utilization of solar radiation, should reduce the need for time consuming multi-factorial field trials. In addition, an understanding of crop growth based on known plant physiological processes makes its quantification more meaningful. Application of this understanding to commercial cropping enables the maximum growth and yield potential of the crop to be exploited. Greenwood *et al.* (1975) provided insights into crop-environment response with growth analysis experiments on Unicrop, one of the first early-flowering crop-type lupin cultivars. These experiments along with density trials (Withers, 1975), time of sowing (Garside, 1979), and effects of moisture stress on lupins (Biddiscombe, 1975) provide a guide to the sort of factors included in this experiment.

The experiment outlined in this chapter provides the basic data necessary to construct a simplified crop growth and yield model for the narrow leafed lupin.

4.2. Aim

(i) To quantify the effects of plant density and the environment on lupin crop growth, development, and yield components.

(ii) To explain these effects using principles of crop physiology.

(iii) To provide data to develop a model capable of simulating lupin crop growth and predicting grain production.

4.3. Materials and Methods

4.3.1. Location of experimental sites

The experiment was located at Elliott and Cressy in 1989 (see Table 3.2 and Appendix A for detailed site descriptions).

4.3.2. Experimental design

Yandee, Geebung, and 75A329 were planted in 20m x 1.5m plots replicated four times at five densities in a randomised complete block design.

4.3.3. Experimental details

The experiment consisted of autumn sowings of lupins at each site. In order to obtain a range of densities, five sowing rates were calculated based on seed weight, germination testing (for Yandee and

Geebung only), and target densities. Details of the sowings at each site are listed in Tables 4.1a and 4.1b.

Table 4.1a. Summary of procedure used in establishing the experiment at Elliott and Cressy.

Site	Elliott	Cressy
Year	1989	1989
Sown	June 13	June 1
Seed rates	See Table 4.1b	See Table 4.1b
Inoculum	Group G	Group G
Fertiliser:		
type	Superphosphate (9.1%)	Superphosphate (9.1%)
rate(kg/ha)	250	250
Herbicide:		
type	Metribuzin	Metribuzin
rate (g ai/ha)	140	250

4.3.4. Weather details

Rainfall, evaporation (class A pan), and temperature data (Fig 4.1) were collected from meteorological stations at Elliott and Cressy. These stations were situated within 500 metres of the experiment sites and were considered representative of weather conditions at the experiment locations.

Table 4.1b. Details of seeding rates (kg/ha) used to approximate target plant densities at Elliott and Cressy.

	Yandee	Geebung	75A329
10 plants/m^2	22	17	13
20 plants/m^2	44	34	26
40 plants/m^2	88	68	52
80 plants/m^2	172	132	104
160 plants/m^2	344	264	208

4.3.5. Data collection

The plot length of 20 metres (1.5 metres wide) allowed 10 metres for sequential sampling throughout crop ontogeny and 10 metres for final machine harvest of the grain. Prior to emergence, the plot area to be harvested regularly was marked out (Plates 4.1 and 4.2). Due to restrictions on resources, only three (10, 40, and 160 plants/m^2) of the five densities were measured throughout crop ontogeny.

During crop growth

Samples were sequentially harvested at 14 day intervals from randomly selected 0.5 m^2 subplots (Fig 4.2). Buffer areas of 50 cm were left either side of each harvested quadrat, and outside rows were also left. Plants were pulled from the ground in the sample area; stems were cut just above ground level and roots discarded.

Plants were partitioned into vegetative, pods, and seed components. Due to the large sample size from harvest five onwards, a subsample

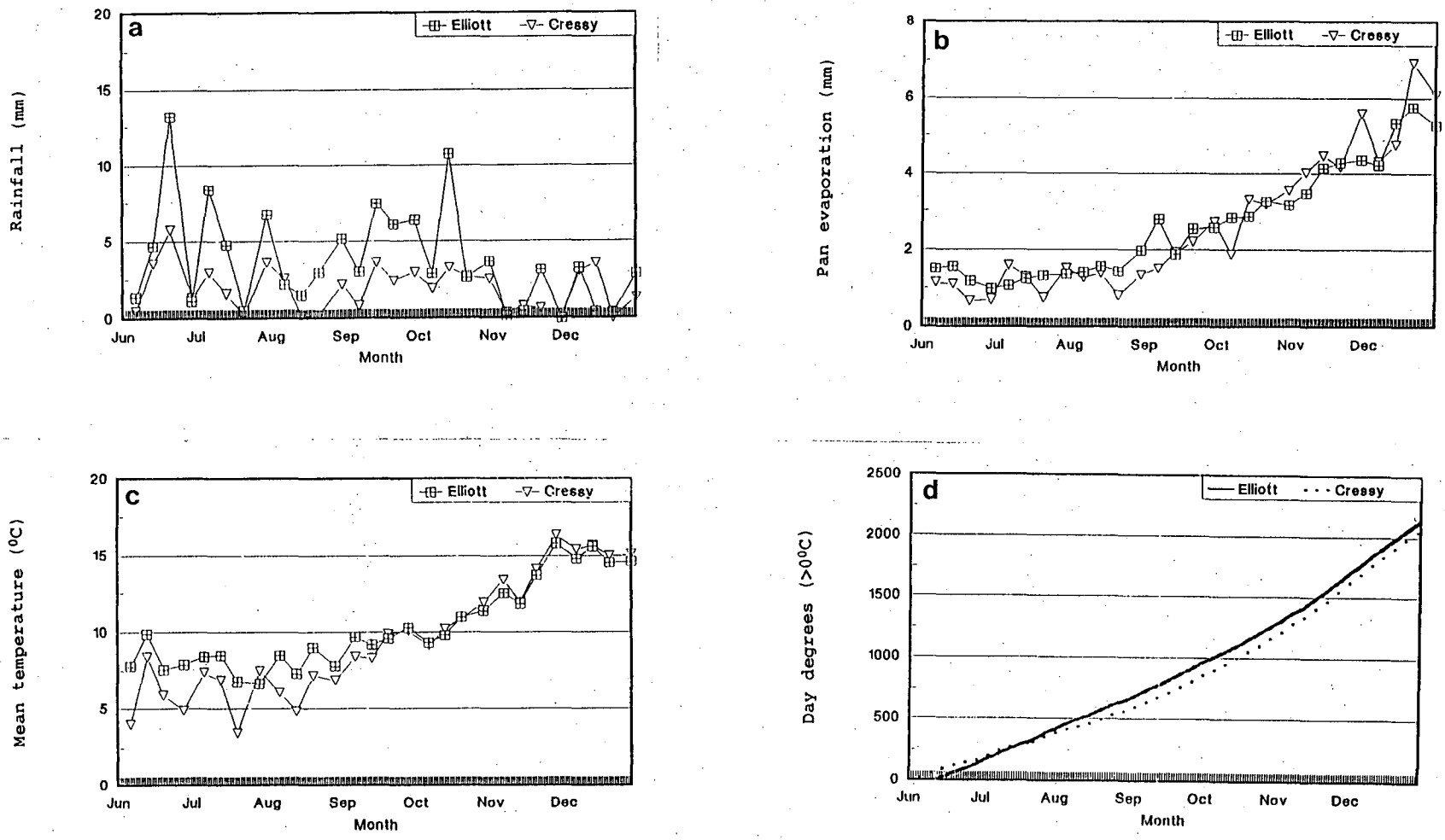

Fig 4.1. Mean weekly weather data (a, b, c) and thermal time (d) measured at each experimental site for 1989/90.

of 25 plants was taken for partitioning. The subsample was calculated as a proportion of the total sample by weight.

The separated plant components were dried at 65 ^{0}C for 48 hours and the dry matter determined. A subsample of fresh leaf was used to measure leaf area using a Paton(R) electronic planimeter.

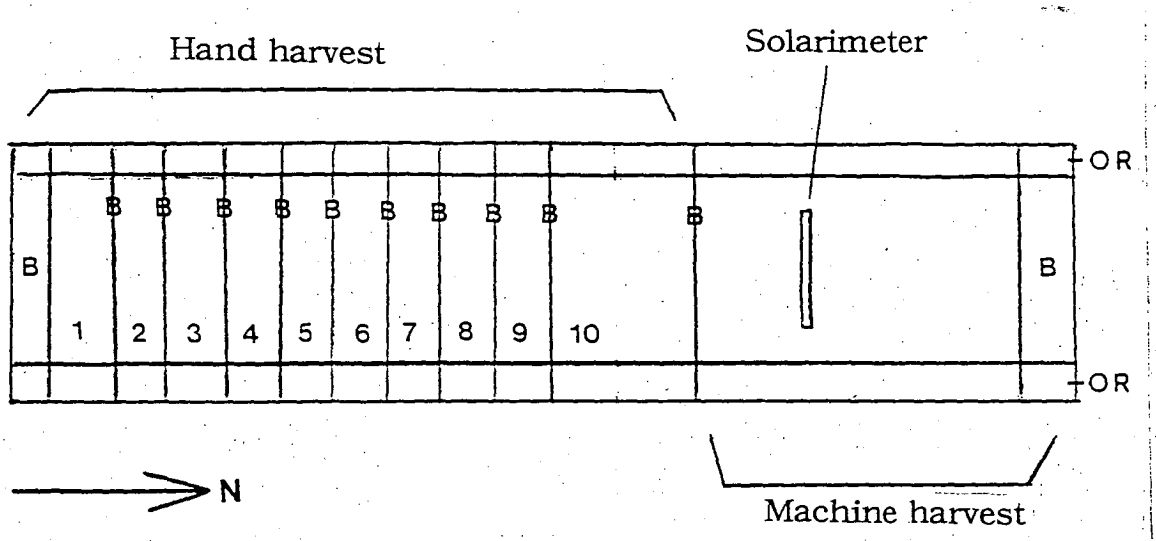

Fig 4.2. Diagram of layout for each plot indicating sample areas and solarimeter positioning. (B = buffer, F = final harvest, OR = outer row, 1 to 10 = plots for randomised sequential harvests)

Light Interception measurements

At each sampling period, light interception measurements were made using tube solarimeters. Three solarimeters were connected in series and placed in a fixed and constant position within the crop at each sampling period. Three of the four replicates were used. The instruments were orientated across the north-south rows (Fig 4.2). Data were collected using a millivolt integrator (Delta(R) Instruments Type MV1). Measurement periods were set at five minutes. Another solarimeter and integrator were set up outside the crop to measure

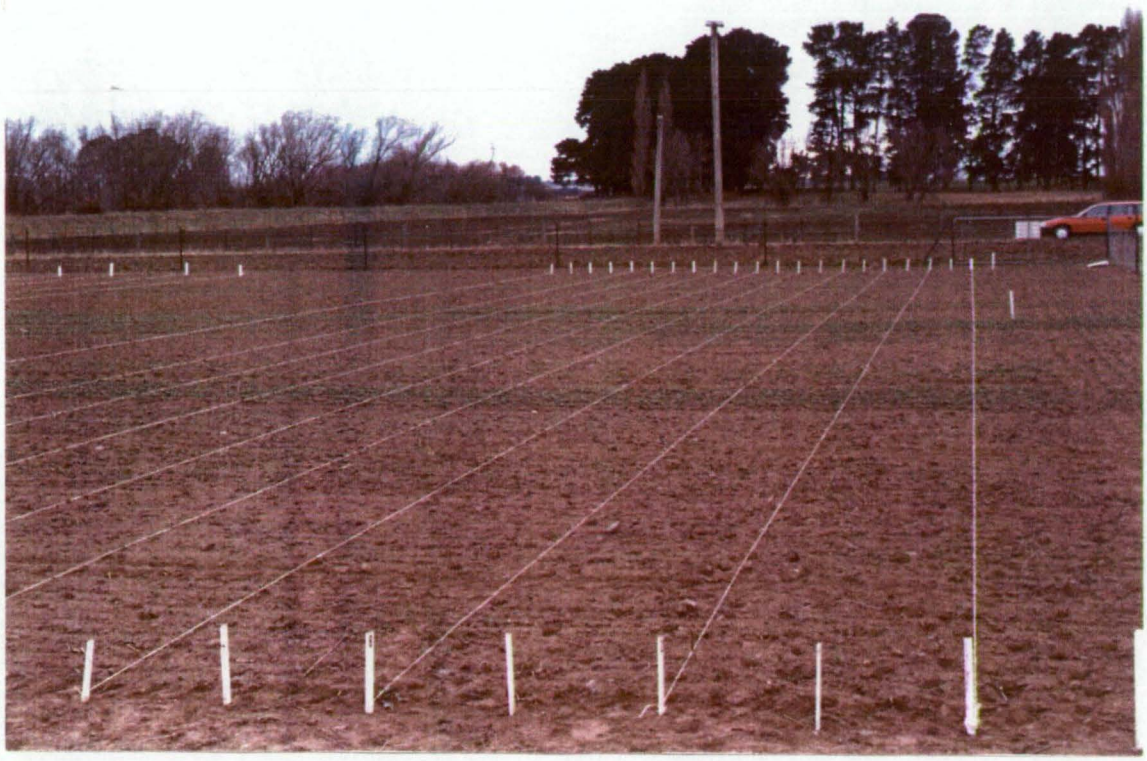

Plate 4.1. Harvest areas marked out using twine.

Plate 4.2. Marker twine did not interfere with lupin plant growth, and ensured accuracy in the areas harvested throughout ontogeny.

incident radiation relative to the in-crop instrument reading during the measurement period.

At crop maturity

The final sequential harvest was collected by hand from a one square metre area buffered on all sides. A subsample of plants was collected and weighed out as a proportion of the total sample and separated into stem and pod (due to senescence no leaves were present). The pods were separated into seed and hull. All plant components were dried as previously mentioned. Seeds were counted and weighed. Grain yield (hand harvest) was calculated for each treatment.

The outside rows of each plot were removed by hand before the remaining 10 metres were headed using a Nurserymaster small plot header. Grain yield (machine harvest) was calculated for each treatment.

Soil water deficit estimates

In the absence of initial soil water measurements, it was necessary to choose a point in time (mid-winter) when soil was most likely saturated (based on climate data), assume field capacity, and set this as a zero starting point for deficit calculations. Pan A evaporation data was modified by multiplying by a crop factor set at 0.3. Prior to branching and canopy development, the crop factor was set at 0.3. As the canopy developed it was increased. At full canopy cover an estimated crop factor of 1.0 was used. Daily estimated evapotranspiration was subtracted from rainfall. Where this was a negative the deficit showed whereas a positive figure was shown as zero (the starting point).

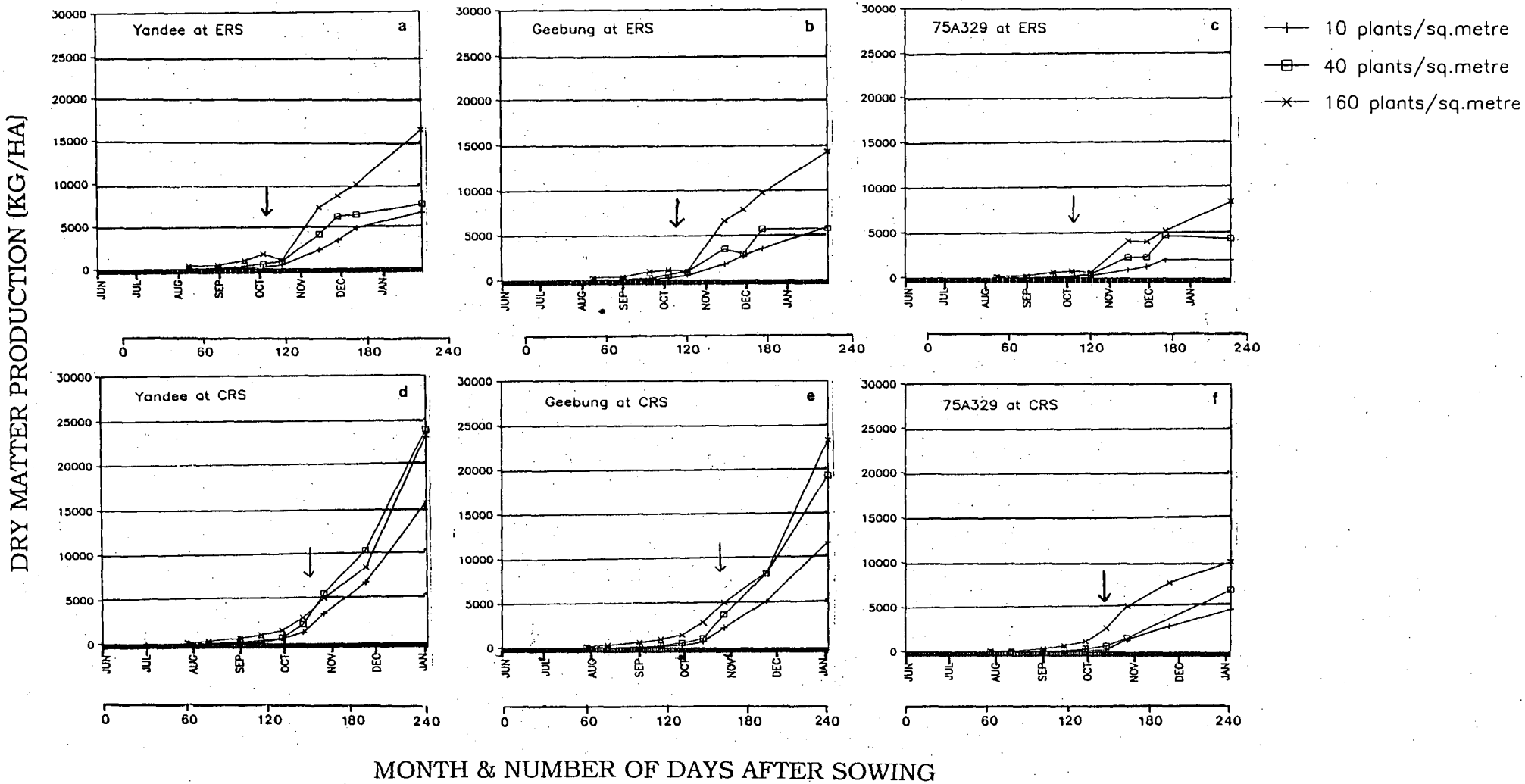

Fig 4.3 Dry matter production (kg/ha) plotted against time (month and days after sowing) for each cultivar at three densities at each site. Arrows mark 50% flowering. ERS = Elliott, CRS = Cressy.

4.4. Results and Discussion

Specific target densities were not reached at Elliott or Cressy although a range of different density groups was achieved (Table 4.2).

Table 4.2. Target densities compared with actual lupin plant densities achieved at each site (E = Elliott, C = Cressy)

	Actual density achieved							
Target dens	Yandee		Geebung		75A329		Mean	
	E	C	E	C	E	C	E	C
10	12	8	13	8	10	4	12	7
20	12.	10	12	9	10	9	11	9
40	25	28	19	16	20	8	21	17
80	57	48	45	39	36	26	46	38
160	117	71	107	64	79	49	101	61

Plant establishment varied between sites, and Elliott tended to have higher plant densities than Cressy. At each site, Yandee numbers were generally the highest and 75A329 the least. This may have been due to low viability or poor vigour of the seed (no germination tests were made on this seed lot).

I will present data showing any overall variation due to site, cultivar, and density effects. Interactions between these three factors will be discussed under each heading.

4.4.1. Site (x cultivar) effects

All crops grow slowly until a cover of leaf area is established, and the slow accumulation of dry matter at both sites for 8-10 weeks after sowing (Fig 4.3) indicated that lupin plants were no different and probably accentuated compared to most other adapted crops. The

slow growth periods observed in the experiment also coincided with the coolest winter months. Rapid dry matter accumulation occurred shortly after flowering had commenced, an apparent characteristic of narrow leafed lupin. Apparent negative growth rates at Elliott just after flowering commenced were probably due to sampling error. Crops accumulated more dry matter at Cressy during the December-January period than at Elliott.

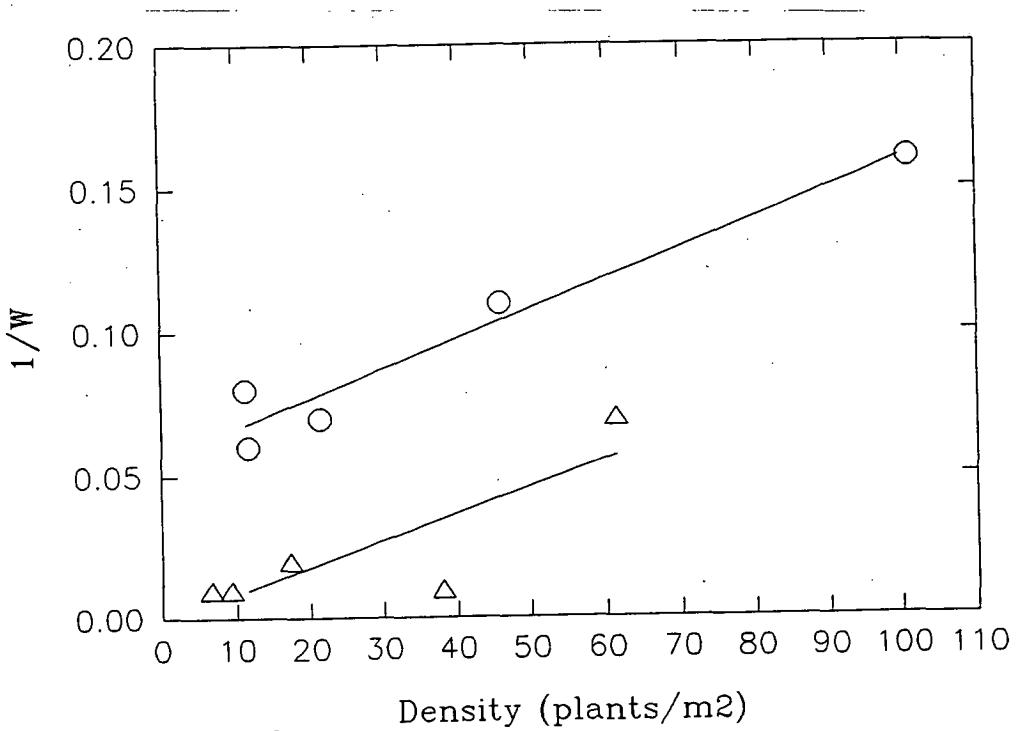

Fig 4.4. Relationships between reciprocal of weight per plant (1/W) at harvest, and density (plants/m^2) averaged over the three cultivars for Elliott (○) and Cressy (△). Fitted line equations are:

(i) $1/W = 0.001$ Density $+ 0.056$ $R^2 = 0.98$

(ii) $1/W = 0.001$ Density $+ 0.001$ $R^2 = 0.99$

Dry matter measurements were made on the five densities at harvest and individual plant weights were averaged over the three cultivars to obtain site differences for plant weight (Fig 4.4). Plants at

Elliott were smaller than plants at Cressy at the same density. In addition, grain yields at Elliott were significantly ($p<0.05$) less than at Cressy (Tables 4.4a and 4.4b on page 55 and 56). Biddiscombe (1975) previously showed small plants set fewer pods and have lower grain yields.

To further investigate site differences in plant size, soilwater deficits were estimated at Elliott and Cressy
(Fig 4.5) to see if the crop at Elliott was more likely to have suffered moisture stress than at Cressy prior to pod set. The estimated water balance indicated sufficient soilwater until well after flowering, with apparently more water available at Elliott so stress was unlikely to have been the explanation for poorer growth at Elliott. At Cressy, however, the crop may also have had access to a water table. During the sampling process when whole plants were removed, visual comparisons were made between root systems on plants taken from Elliott and Cressy. The Cressy plants had a thicker longer tap root and more extensive lateral root system compared with plants at Elliott. It was established that the Cressy experiment was located on an area with a shallow water table (Ian Bell, DPIF, personal communication). An examination of soil types and the nutrient status (Appendix A) of both sites showed twice the level of phosphate at Cressy compared with Elliott. The krasnozem soil at the latter is capable of fixing large quantities of applied phosphate. Rahman and Gladstones (1974) have demonstrated significant yield response of lupins with increased application rates of superphosphate.

A combination of lower density, more nutrients, and access to groundwater late in the season and the higher temperatures at Cressy may have been factors contributing to larger higher yielding plants at Cressy.

Cultivar flowering times hardly differed between sites (Table 4.3). The winter period at Elliott was warmer (Fig 4.1c), so Elliott accumulated more day degrees than Cressy (Fig 4.1d). Studies by Downes and Gladstones (1984b) found an optimum flowering temperature for lupins between 16°C and 21°C. Although this suggested that sites that vary in temperature will also differ in flowering time, cultivars at Cressy reached 50% flowering with more day degrees than at Elliott (Table 4.3), however the difference was not statistically significant. This was probably a function of earlier planting at Cressy. This suggests that flowering was influenced by photoperiod as well as temperature. The later flowering of Geebung at each site is presumably due to a vernalisation response for which the efl gene is responsible.

The larger plants at Cressy expanded more leaf area during the October-November period (Fig 4.6). This result is consistent with the larger plants producing more leaves. The relationship between leaf

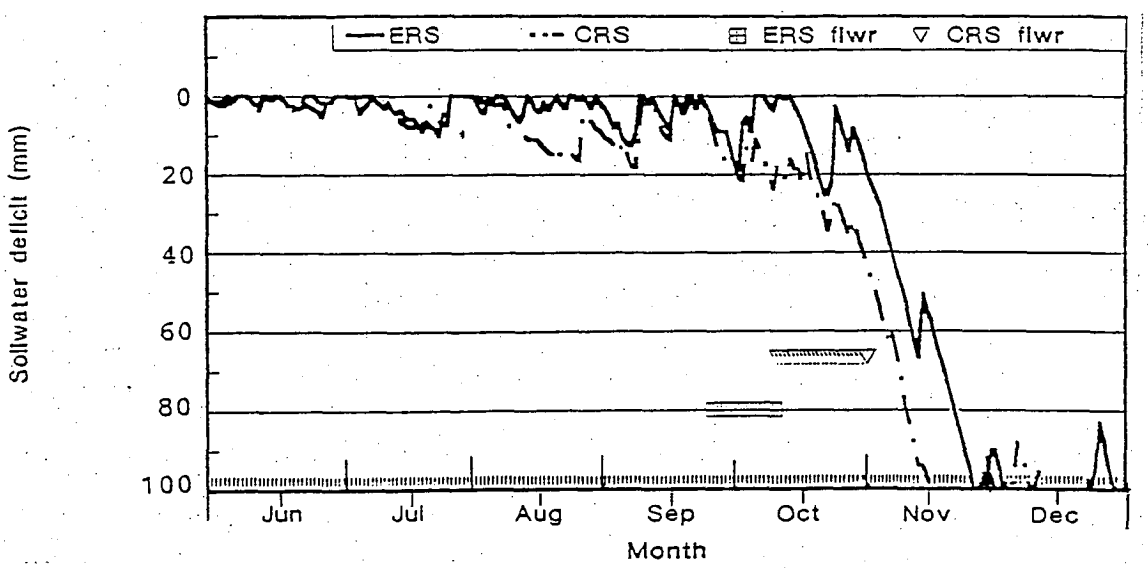

Fig 4.5. Estimated soilwater deficits (mm) for both sites during the crop season. The period of flowering at each site is overlaid on graph.

Table 4.3. A comparison of day degrees (>0°C)accumulated for lupin cultivars from time of sowing until 50% flowering, as well as approximate date of flowering, at each site.

Site	Yandee	Geebung	75A329	Mean
Elliott	887 (20 Oct)	947 (24 Oct)	887 (20 Oct)	907
Cressy	958(19 Oct)	1114(26 Oct)	958(19 Oct)	1010

Nb: Elliott site sown 13th June, Cressy site sown 1st June

area and the ln% of transmitted light indicates similar relationships between sites (Fig 4.7). The higher extinction coefficient at Cressy may be due to differences in leaf angle and stem interference in light transmission due to lower densities, and more branching. Although the radiation measurements provided useful data on leaf area development of plants in each treatment, continuous incident radiation measurements across the growing season would enable full use of this data. Such measurements were planned for the second year of measurements, and are referred to in chapter five.

4.4.2. Density (x cultivar) effects

4.4.2.1. Leaf area and light interception

Data from experiments by Zaffaroni and Schneiter (1989), and Tetio-Kagho and Gardener (1988) indicated that lower plant densities have less leaf area to intercept light. In this experiment, the development of leaf area index (L) of the three

lupin cultivars was plotted throughout their growth (Fig 4.6). The lupin plants at the highest density (160 plants/m^2) produced the highest L throughout most of the season. L also peaked at these higher densities and decreased towards the end of the season. Plants at the lower densities (10 and 40 plants/m^2) either reached an L peak later or continued to increase towards the end of the season. The decrease in L was due to leaf abscission, a normal process in lupins that occurs as the plant matures and starts to dry out. Clearly, crops of high density plants can maximise their L throughout the growth season and will show earlier leaf abscission and maturity, possibly as a result of curtailed branching and flowering.

The difference between the percentage of light intercepted by each of the three lupin plant densities measured in this experiment was shown when the leaf area was plotted against ln% of transmitted light throughout crop growth and development (Fig 4.8). The light extinction coefficients varied with plant density, with the lowest coefficient measured at the highest density. Variation in the extinction coefficient relates to plant density effects on leaf angle and stem proportion. Areas of leaves only were measured in this experiment. A larger proportion of stems in high density plantings would probably give an apparently greater interception by a given layer of leaves L, therefore much of the variation is probably due to leaf angle effects.

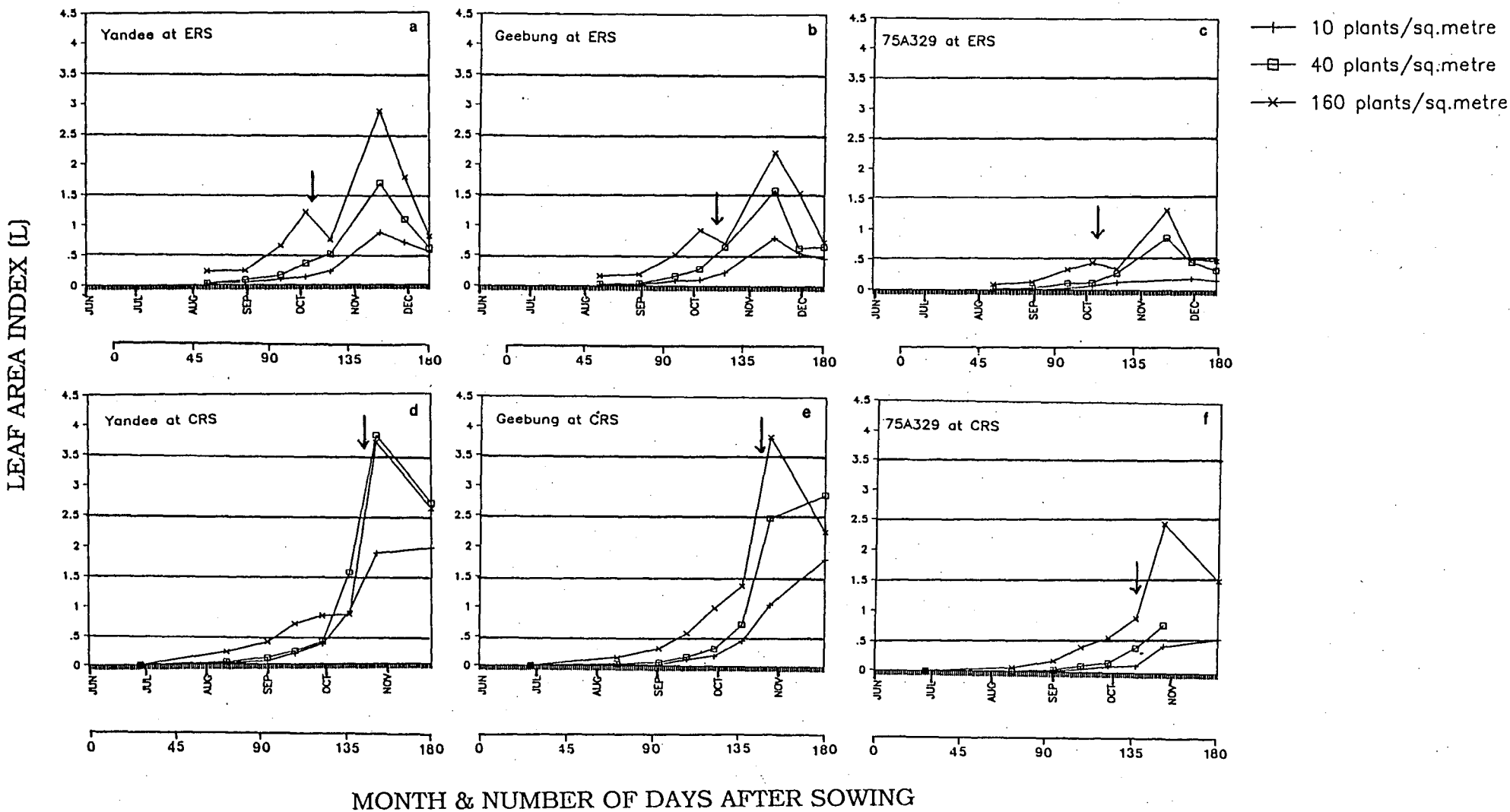

Fig 4.6 Leaf area index (L) plotted against time (month and days after sowing) for each cultivar at three densities at each site. Arrows mark 50% flowering. ERS = Elliott, CRS = Cressy.

4.4.2.2. Dry weight per plant

In addition to affecting leaf area, a plant's individual dry weight varies according to the density of plants in the community to which that individual belongs. To determine the relationship between individual lupin plant weight and the lupin plant density, this relationship was plotted for each site (Fig 4.4) and each cultivar (Fig 4.9) at harvest. The plots are highly correlated, but show dry weight/density relationships that differ according to cultivar (discussed in section 4.4.3 Cultivar effects) and site. The plots indicate that as plant density increases, plant size and weight decreases. Frappell (1979) provides a clear explanation for this response in his review of plant density effects and competition. Increased plant population decreases the availability of resources to each plant. This decrease in resources is reflected in a decrease in plant size and weight.

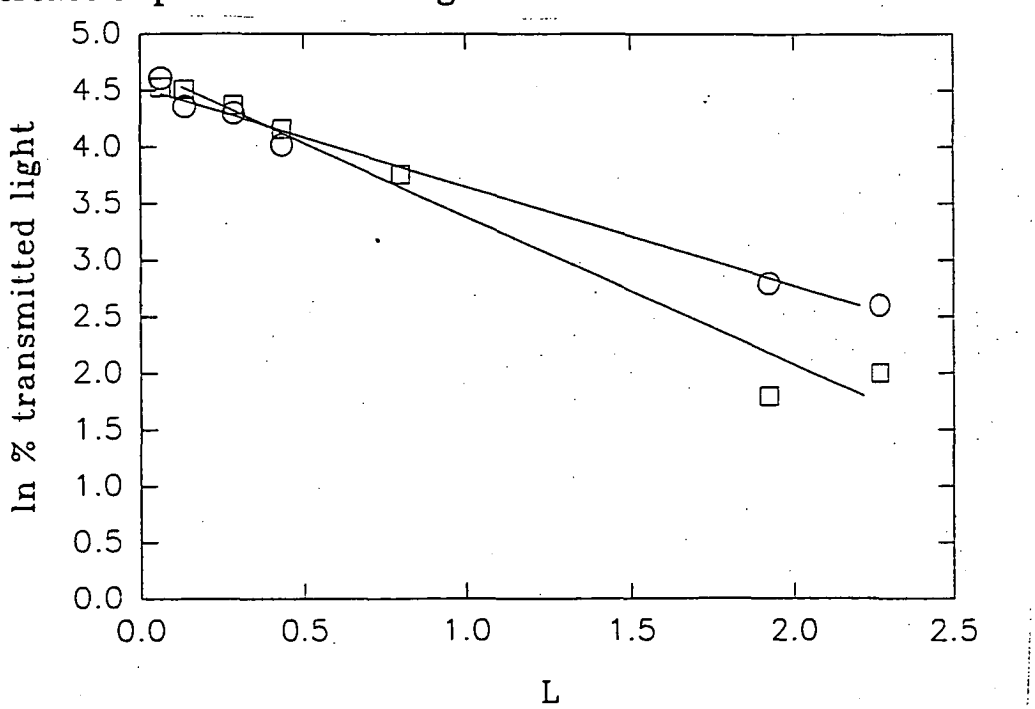

Fig 4.7. Relationships between ln% of transmitted light and leaf area index (L) averaged over three cultivars and three densities for (i) Elliott (○), and (ii) Cressy (□). Fitted lines are:

(i) ln% transmitted light = -0.873 L + 4.5 $R^2 = 0.95$

(ii) ln% transmitted light = -1.304 L + 4.7 $R^2 = 0.98$

4.4.2.3. Yields and components

Clapham and Elbert-May (1989) showed that plant density had a significant influence on seed and total plant yields of sweet white lupins (*Lupinus albus*). In their introduction to their experiment they stated that higher densities in narrow-leaf lupin populations contribute towards decreased lateral branching similar to the white lupin. Their comments as well as the plant weight/density relationships detailed in this experiment show plant density to be a key factor of lupin grain yield, suggesting the existence of an optimum density (Fig 4.10 a,b on page 55). To determine what yield components were most affected by

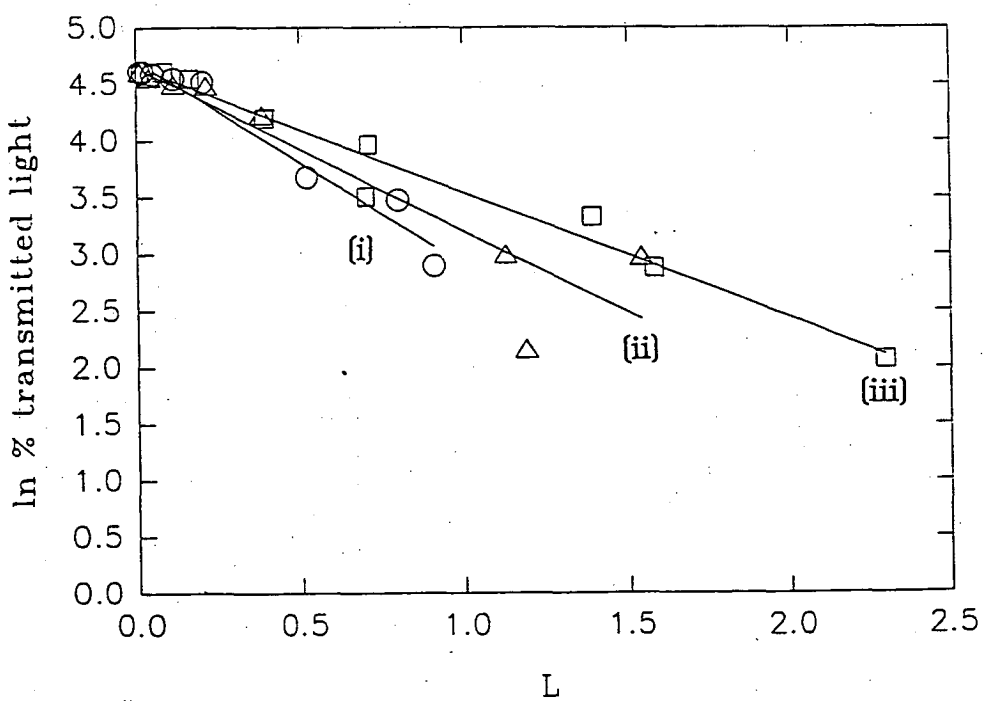

Fig 4.8. Relationships between ln% of transmitted light and leaf area index averaged over three cultivars and two sites for (i) 10 (○), (ii) 40 (△), (iii) 160 (□) plants/m².

Fitted lines are:

(i)	ln% transmitted light = -1.78 L + 4.7	$R^2 = 0.90$
(ii)	ln% transmitted light = -1.44 L + 4.7	$R^2 = 0.92$
(iii)	ln% transmitted light = -1.10 L + 4.7	$R^2 = 0.98$

Table 4.4a. Yield component data for Yandee, Geebung, and 75A329 at Elliott. (n.s. = not significant)

Cultivar	Target plant/m²	Actual plant/m²	Pods/m²	Pods/plant	Seeds/pod	100 seed (g)	Grain Yield (kg/ha)	Totaldry (kg/ha)
Yandee	10	12	233	19.1	3.71	17.8	1544	3215
Yandee	40	25	281	11.5	3.36	18.3	1739	3708
Yandee	160	117	509	4.4	3.27	19.8	3324	8011
	$LSD_{0.05}$	*22.72*	*103*	*4.9*	*0.24*	*0.91*	*685*	*1876*
Geebung	10	13	230	16.9	3.77	16.1	1475	2902
Geebung	40	19	239	13.0	3.67	15.9	1421	2829
Geebung	160	107	506	5.0	3.54	17.4	3143	7079
	$LSD_{0.05}$	*30.16*	*58*	*5.0*	*n.s.*	*n.s.*	*376*	*741*
75A329	10	10	106	10.4	3.19	14.3	485	1018
75A329	40	20	224	11.1	3.40	14.0	1088	2211
75A329	160	79	430	5.5	3.36	14.5	1855	4281
	$LSD_{0.05}$	*28.12*	*159*	*3.0*	*n.s.*	*n.s.*	*638*	*156*
Yandee		51.17	341	11.6	3.45	18.6	2202	4978
Geebung		46.08	325	11.6	3.66	16.4	2013	4270
75A329		36.42	253	9.0	3.21	14.2	1142	2503
$LSD_{0.05}$		*n.s.*	*n.s.*	*n.s.*	*0.39*	*1.69*	*155*	*397*

Table 4.4b. Yield component data for Yandee, Geebung, and 75A329 at Cressy. (n.s. = not significant)

Cultivar	Target plant/m²	Actual plant/m²	Pods/m²	Pods/plant	Seeds/pod	100 seed (g)	Grain Yield (kg/ha)	Totaldry (kg/ha)
Yandee	10	8	428	57.1	4.15	16.0	2830	7950
Yandee	40	29	652	25.2	3.78	17.8	4482	12000
Yandee	160	71	524	7.3	3.68	18.7	3615	11670
	$LSD_{0.05}$	*19.92*	*n.s.*	*21.5*	*n.s.*	*1.8*	*n.s.*	*n.s.*
Geebung	10	8	508	60.3	4.41	16.6	1638	8180
Geebung	40	16	513	31.4	3.94	18.5	3590	9700
Geebung	160	64	565	10.0	4.10	17.2	3893	10570
	$LSD_{0.05}$	*17.07*	*n.s.*	*25.0*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
75A329	10	4	148	37.3	3.89	15.7	989	2410
75A329	40	8	322	30.5	4.07	13.9	1377	4240
75A329	160	49	452	10.3	3.78	14.1	2413	5070
	$LSD_{0.05}$	*19.26*	*199*	*20.3*	*n.s.*	*n.s.*	*1419*	*n.s.*
Yandee		35.92	534	29.8	3.87	17.4	3642	10540
Geebung		30.33	528	33.9	4.15	17.4	3751	9483
75A329		21.08	307	26.0	3.93	14.5	1741	3906
$LSD_{0.05}$		*n.s.*	*272*	*n.s.*	*n.s.*	*3.3*	*1798*	*4345*

changes in plant density, yield components for each cultivar, density, and site were statistically analysed (Tables 4.4 a & b). The grain yields shown in these tables were calculated from the other measured yield components. As a result only the three densities measured throughout growth are included, but Fig 4.10 shows a range of harvested grain yields and illustrates optimum density. At Elliott, increases in plant density resulted in significant increases in grain yield (Fig 4.10). The increased number of plants/m^2 resulted in fewer pods/plant but pods/m^2 increased (Table 4.4a). At Cressy where numbers of pods/m^2 were larger at all densities, and the spread of actual plant densities on the indeterminate cultivars was not as large, an increase in the plant density maintained the number of pods/m^2 at a similar number compensating for significant decreases in pods/plant. There were no

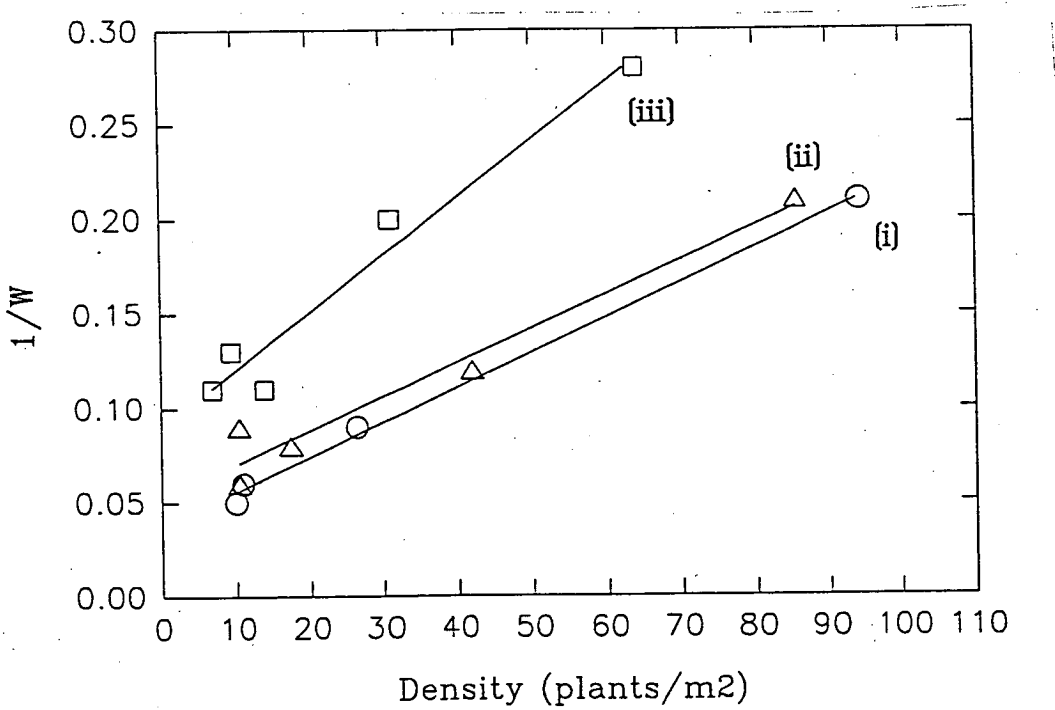

Fig 4.9. Relationship between reciprocal of plant weight at harvest (1/W) and plant density (plants/m^2) averaged over the two sites for (i) Yandee (○), (ii) Geebung (△) and (iii) 75A329 (□).

The fitted line equations are:

(i) $1/W = 0.002$ Density $+ 0.037$ $\quad r^2 = 0.99$

(ii) $1/W = 0.002$ Density $+ 0.052$ $\quad r^2 = 0.98$

(iii) $1/W = 0.003$ Density $+ 0.090$ $\quad r^2 = 0.98$

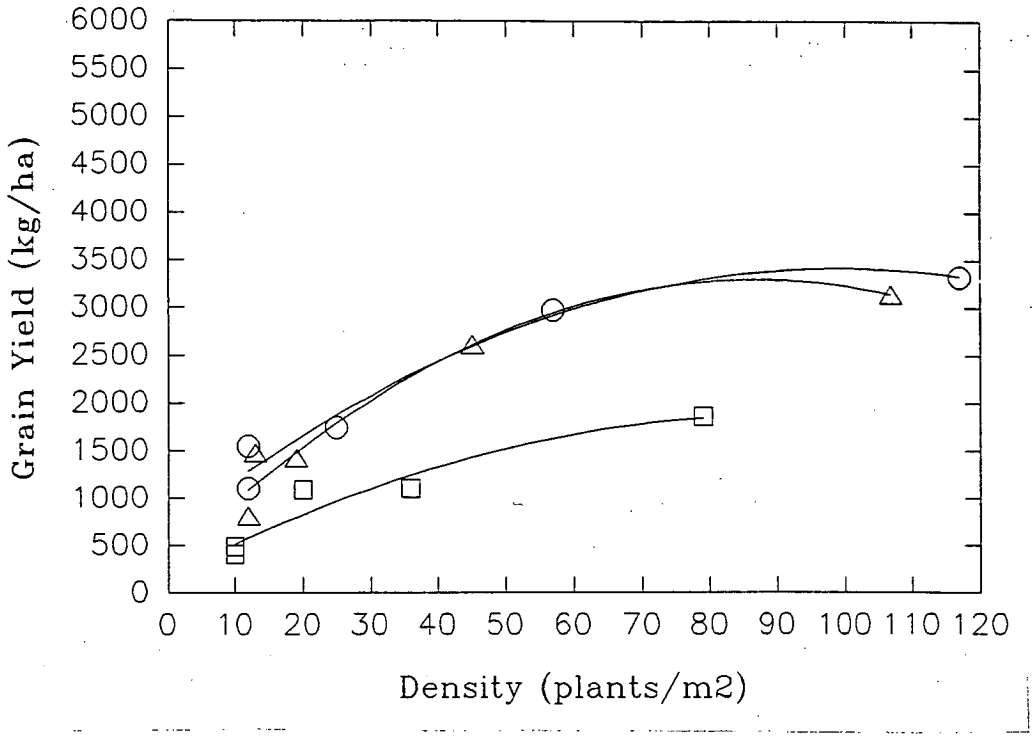

Fig 4.10a. Relationship between grain yield at harvest (kg/ha) and actual lupin plant densities at Elliott for Yandee (○), Geebung (△), and 75A329 (□). Computer generated spline curves fitted.

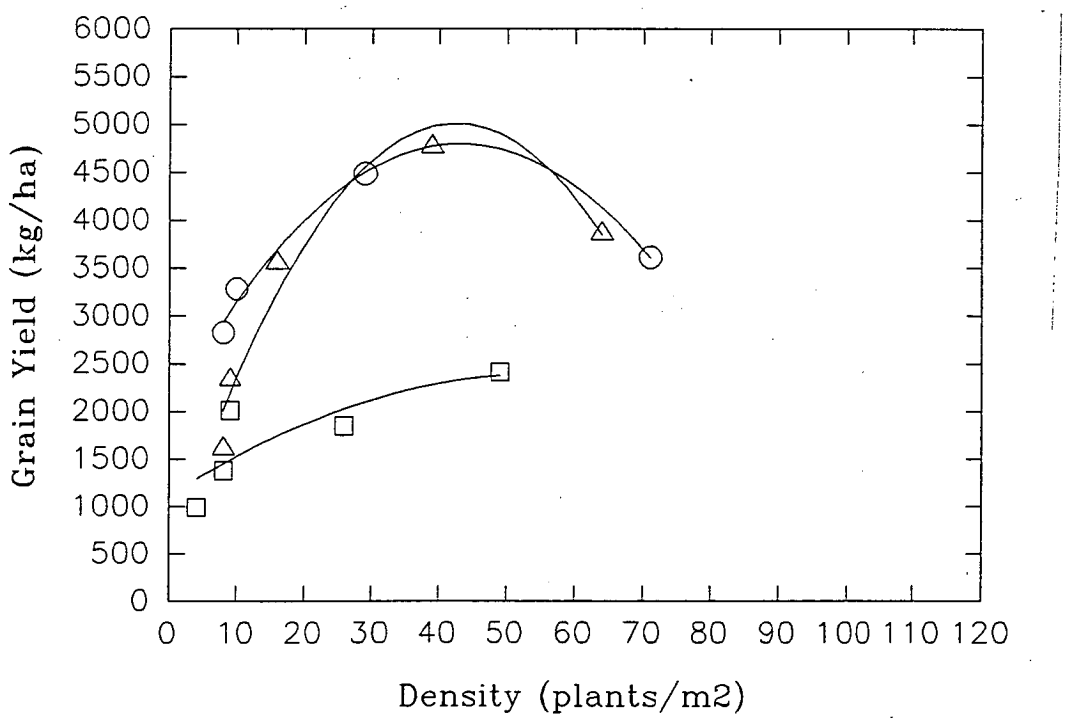

Fig 4.10b. Relationship between grain yield at harvest (kg/ha) and actual lupin plant densities at Cressy for Yandee ○, Geebung (△), and 75A329 (□). Computer generated spline curves fitted.

significant decreases in the number of pods/m^2, or the grain yields calculated from the other yield components, at the high density indicating grain yield is a function of pods/m^2 rather than pods/plant.

At Elliott, with poorer plant growth, yields kept increasing for all cultivars with increased density (Fig 4.10a). This indicates an optimum plant density was not reached under these conditions. At Cressy under better growth conditions, grain yield peaked at an optimum plant density of 30 to 40 plants/m^2 (Fig 4.10b). The determinate type had not reached an optimum plant density at this point. Due to its branching structure, a much higher optimum plant density may be required, although the slope of the fitted line suggests that any further increase in grain yield may not be significant.

4.4.3. Cultivar effects

The cultivar genotype characteristic that resulted in the most notable differences in growth and development was branching type. Plots of dry matter production over time (Fig 4.3) show the indeterminate cultivars, Yandee and Geebung, were similar in their accumulation, while the determinate cultivar, 75A329, accumulated less dry matter. The final dry matter production of 75A329 was significantly ($p>0.05$) lower than Yandee or Geebung (Table 4.4 a & b). The lower dry weight indicates smaller plants, and this was confirmed when the reciprocal of individual plant dry weight was plotted against density for each cultivar (Fig 4.9). This graph clearly indicated the size similarity of Yandee and Geebung, and the difference of 75A329. Plots of L over time (Fig 4.6) showed less leaf area development at each density for the determinate 75A329. L development prior to flowering indicates the process is much slower compared to the indeterminate cultivars. At the highest density, an increase in L occurred immediately after flowering. However at lower

densities, compared with the indeterminate cultivars, L did not increase after flowering. Yandee and Geebung were very similar in their L development. With these cultivars, L continued to increase over a longer time period at lower densities probably due to further branching. This was not observed in the high density plots due to competitive effects previously described.

As a result of 75A329's smaller size, ie dry matter, at each density, it set a significantly ($p<0.05$) lower yield of grain compared to Yandee and Geebung. This could be due to the reduced branching characteristic of 75A329 being a disadvantage in long season environments. At Cressy, for example, the plants apparently had access to groundwater and nutrients late into the season and the indeterminate cultivars were able to continue flowering on higher order branches. 75A329 was limited in its potential pod set sites, and was unable to take advantage of favourable conditions late into the season.

A further factor contributing to lower yield of 75A329 was its significantly smaller ($p<0.05$) seed which did not compensate for fewer pods/m^2.

75A329 showed significant increases in the number of pods/m^2 with increasing density resulting in significant grain yield increases. Yandee tended to show a slight increase in seed weight at higher densities indicating potential for increasing seed size by reducing pod set/plant.

Although Geebung flowered later than the other two cultivars, this difference did not correlate with differences in yield.

Finally, comparisons of light extinction coefficients (Fig 4.11) for each cultivar, indicated similar extinction coefficients for all cultivars. The variations between cultivar extinction co-efficients should relate to differences in leaf angles or arrangements on the plants. Whether the cultivar is a determinate or indeterminate type appears to have very

little effect on extinction coefficients. There is a bigger difference in extinction coefficients between the two indeterminate cultivars than between indeterminate Geebung and determinate 75A329.

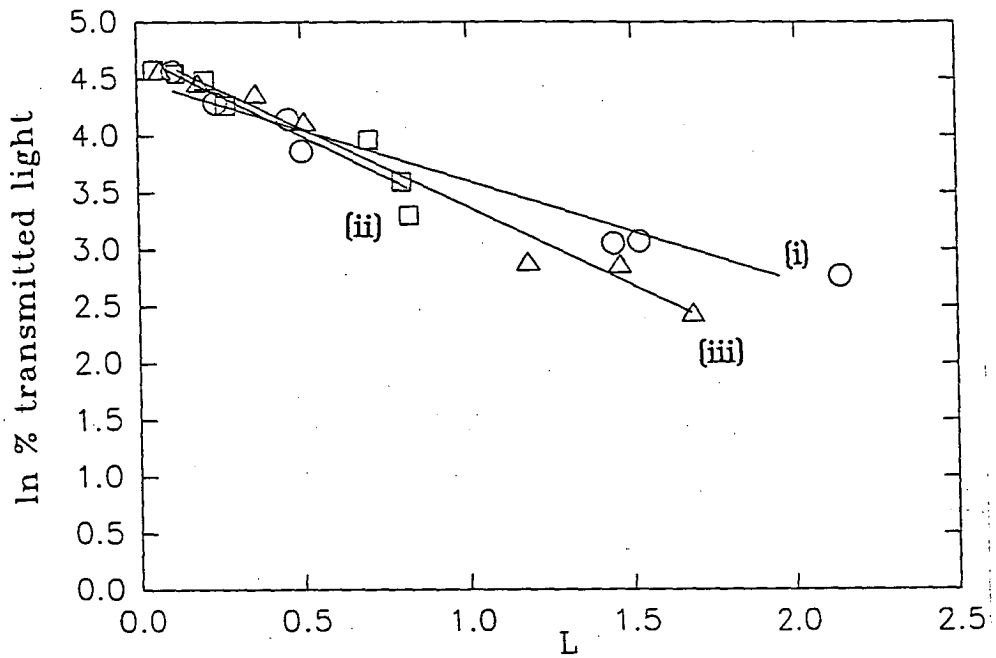

Fig 4.11. Relationships between ln% of transmitted light and leaf area index (L) averaged over both sites and three densities for (i) Yandee (○), (ii) Geebung (△), and (iii) 75A329 (□).

The fitted lines are:

(i) ln% transmitted light = -0.889 L + 4.5 R^2 = 0.98

(ii) ln% transmitted light = -1.375 L + 4.8 R^2 = 0.99

(iii) ln% transmitted light = -1.430 L + 4.7 R^2 = 0.95

4.5. Conclusions

Higher grain yields were achieved at Cressy possibly due to a combination of larger deep rooted plants with access to more groundwater late in the season. At Elliott, grain yield/ha increased with increasing density despite a decrease in plant size. As the plants became smaller, the number of pods/plant decreased. This was due to less branching, resulting in a lower number of potential pod set locations. Although the determinate 75A329 was expected to be less

susceptible to this, the data indicated significant decreases in pod number per plant as density decreased. This probably reflects smaller plants with shorter mainstem (and less potential pod-set locations) due to increased resource demand. Significantly smaller seed produced by 75A329 contributed to a yield lower than Yandee or Geebung.

At Cressy, densities achieved were much lower than Elliott but plant growth was better. There was evidence at Cressy that under good growth conditions, optimum density for indeterminate cultivars was 30 to 40 plants/m^2. Optimum density for determinate cultivars may be higher than this as peak grain yields were not reached. However, grain yield increases may not be significant.

Overall, increased grain yield is a function of higher numbers of pods/m^2. The indeterminate cultivars are more suited to the Tasmanian situation than the determinate type tried here due to their ability to maximise the benefits of extended cropping seasons. The determinate type would need to be tested at much higher densities to see if comparable yields could be achieved to those of the indeterminate cultivars, but extra seed costs would probably make this uneconomic.

The experiment has provided data on differences in growth and development of lupins at two sites differing in soil type and climate. It has shown significant variation in lupin growth due to density, and has demonstrated different growth responses of selected lupin cultivars. These responses will be explored further in a similar experiment but in a different season (chapter 5). The data in both experiments will form the basis for a simple lupin crop growth simulation in chapter six.

CHAPTER FIVE

THE EFFECT OF PLANT DENSITY AND ENVIRONMENTAL FACTORS ON LUPIN CROP GROWTH AND DEVELOPMENT AT TWO SITES IN TASMANIA (1990)

5.1. Introduction

The experiment detailed in this chapter is similar in most respects to that described in Chapter Four. Principally, the same growth analysis data have been collected. In addition, seasonal comparisons were made between both sites for each experiment. Grain yield only was measured at final harvest.

The experiment outlined in this chapter provides the data for a second season necessary to construct a simplified crop growth and yield model for the narrow leafed lupin.

5.2. Aim

(i) To quantify the effects of the environment on lupin crop growth, development, and grain yield.

(ii) To explain these effects using principles of crop physiology.

(iii) To compare the results of last season with the findings in this experiment.

(iv) To provide data to develop a set of models that will simulate lupin crop growth and grain production.

5.3. Materials & Methods

The location, experimental design and details are set out in Chapter Four with the following variations. The Elliott trial was sown on 15th May 1990 and Cressy was sown on 8th May 1990. Three target plant densities (10, 40, and 160 plants/m^2) were used instead of five. Yandee, Geebung, and 75A329 were planted in 20m x 1.5m plots replicated three times, instead of four, in a randomised complete block design. Gesatop(R) (500 g simazine/l) was used in place of Sencor to provide improved weed control.

5.3.1 Weather details

At Elliott, all weather data were collected at the local meteorological station situated approximately 1 km northwest of the experiment (Fig 5.1). At Cressy, weather data collection was halted due to closure of the Cressy meteorological station part way through the experiment. All weather data used for Cressy (Fig 5.1) in this experiment were collected at the Launceston airport approximately 20 km northeast of the experiment.

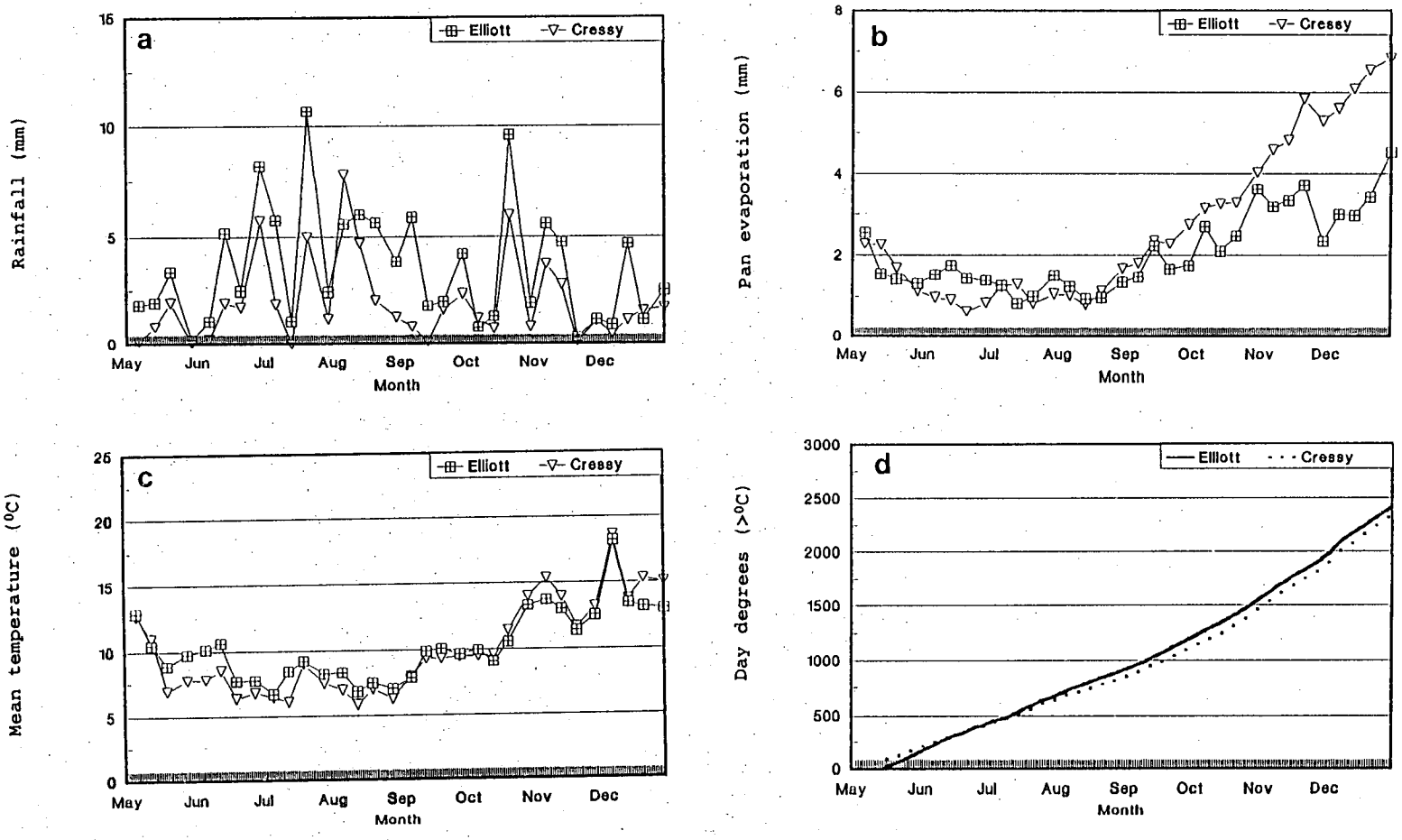

Fig 5.1. Mean weekly weather data (a, b, c) and thermal time (d) measured throughout the experiment season. Cressy weather data collected at Launceston airport.

5.3.2. Data collection

Sampling biomass during growth was similar to the procedure detailed in Chapter Four. In this experiment, plots were sampled non-randomly to minimise disturbing the remainder of the crop during growth.

During crop growth

Based on the experience of last season's experiment, a sub-sample of twenty five plants was taken from each sample of 0.5 m^2 for partitioning up until harvest four. Twenty plants were sub-sampled for each harvest thereafter.

The separated plant components were dried at 65^{0}C for at least 48 hours and dry matter determined. Before drying the leaf portion, a subsample of fresh leaf was used to determine leaf area using a Paton electronic planimeter.

Light interception measurements

These were as detailed in Chapter Four.

Incident radiation measurement

A single tube solarimeter and integrator were set up at each site to provide a daily cumulative total for solar irradiance.

At crop maturity

The site at Elliott was damaged by livestock prior to machine harvest. Accurate machine and hand harvest figures are unavailable for this site. At Cressy, the final sequential harvest was one square metre in area buffered on all sides. A subsample of plants was collected and grain yield (hand harvest) calculated for each treatment. The

remaining ten metres of plot length was headed using a Nurserymaster small plot header.

Soil water deficit estimation

This was detailed in Chapter Four

5.4. Results and Discussion

The data presented in this experiment are similar to that shown in Chapter Four. Similarly to last season, specific target densities were not reached at Elliott or Cressy, although a range of densities was achieved (Table 5.1).

Table 5.1. Target densities compared with actual lupin plant densities achieved at each site (E = Elliott, C = Cressy)

	Actual density achieved							
Target density	Yandee		Geebung		75A329		Mean	
	E	C	E	C	E	C	E	C
10	13	11	12	2	11	8	12	7
40	24	27	19	46	20	37	21	37
160	123	103	103	105	88	94	105	101

The reason for collecting data in the same manner was to obtain further data on lupin growth and development responses over more than one season. The data for this experiment will be presented

showing any overall variations due to site, cultivar, and density effects. Interactions between these factors will also be discussed under each heading. The differences detected will be compared between the 1989 and the 1990 experiments.

5.4.1. Site (x cultivar) effect

Dry matter accumulated slowly at both sites for 8-10 weeks after sowing (Fig 5.2). It was not until October that the plants at Cressy started producing higher levels of dry matter than at Elliott probably in response to higher temperatures (Fig 5.1 c). Prior to that time (and prior to flowering), the development stages of plants at Elliott were further advanced than at Cressy. Lower winter temperatures (Fig 5.1 c) at Cressy would have been the reason for slower initial growth. However, plants at Cressy were larger than those at Elliott just before final harvest (Fig 5.3).

Flowering commenced at Elliott with more day degrees accumulated than at Cressy (Table 5.2), the reverse to the previous season. This indicates possible photoperiod and/or vernalisation effects. The 50% flowering dates differed between sites by 7 to 12 days (Table 5.2). Daylength differences between Elliott and Cressy are unlikely to account for the different flowering times as latitude is almost the same and planting dates were only a week apart. Vernalisation effects are unlikely in Yandee and 75A329 as the Ku gene is present (Gladstones, 1982). Geebung has a vernalisation requirement, and it reached 50% flowering later than the other cultivars, particularly at Elliott. More day degrees accumulated for each cultivar at each site compared with last years experiments (chapter four). As the sites were sown approximately one month

earlier this season, flowering appeared to be due more to a photoperiod effect rather than the day degree accumulation. At Elliott with its warmer winter temperatures, Yandee and 75A329 flowered much more quickly than Geebung that required vernalisation. However at Cressy, flowering times differed only slightly because with Cressy's colder winter temperatures Yandee and 75A329's development was delayed, so that Geebung's vernalization requirement made little difference at this site.

Table 5.2. A comparison of day degrees above a base temperature of 0°C accumulated for lupin cultivars from sowing to reach 50% flowering as well as approximate date at each site.

Site	Yandee	Geebung	75A329	Mean
Elliott	1444 (2 Oct)	1796 (26 Oct)	1444 (2 Oct)	1561
Cressy	1087 (9 Oct)	1210 (14 Oct)	1087 (9 Oct)	1128

Nb: Elliott site sown 15th May, Cressy site sown 8th May.

It is possible that the lower Cressy temperatures prior to flowering caused a delay in development of flower buds. Warmer temperatures at Elliott earlier in the season resulted in the earlier development of flower buds. Thus the plants at Elliott were further developed than those at Cressy and were able to initiate flowering sooner, in response to the lengthening days and increase in air temperature.

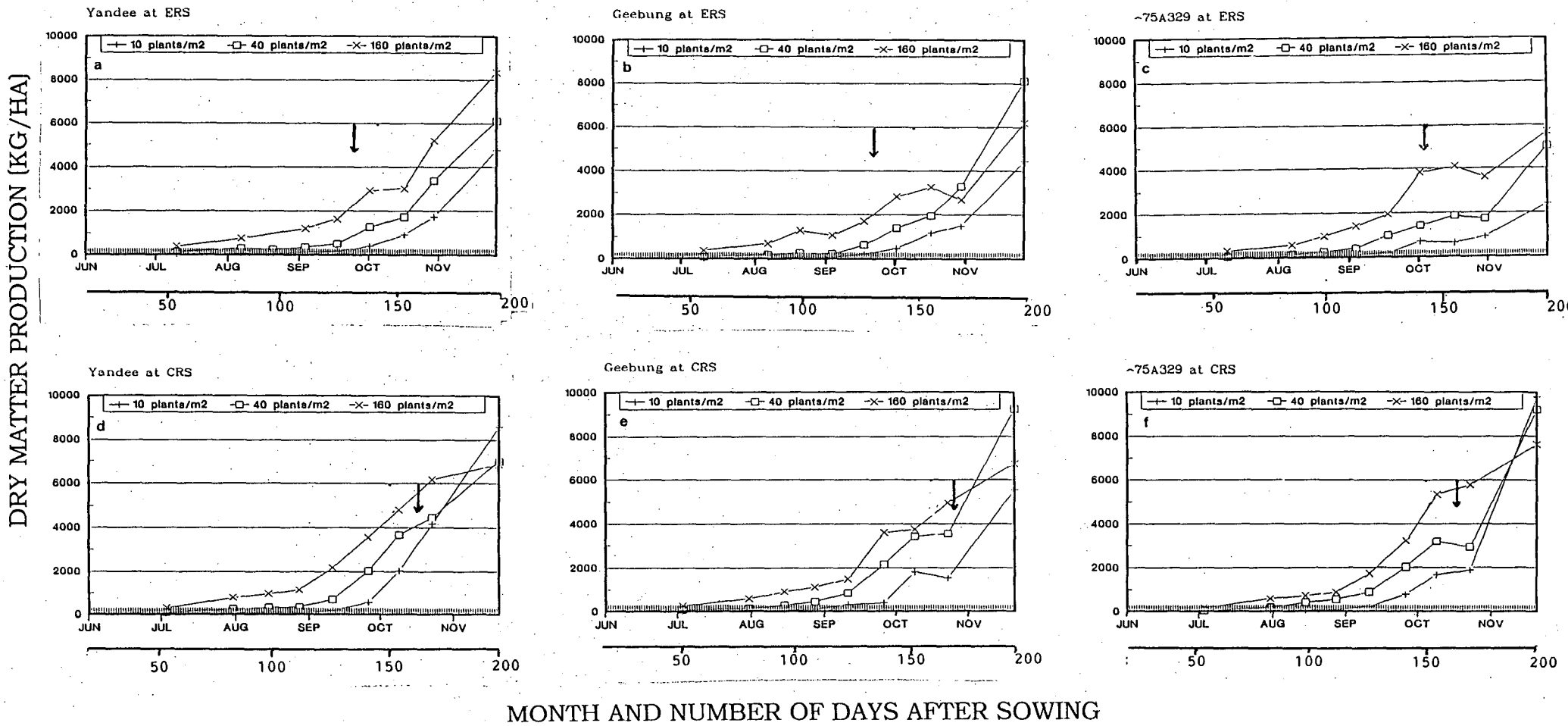

Fig 5.2. Dry matter production (kg/ha) plotted against time (month and days after sowing) for each cultivar at three densities at each site. Data for final harvest not available. Arrows mark commencement of flowering. ERS = Elliott, CRS = Cressy.

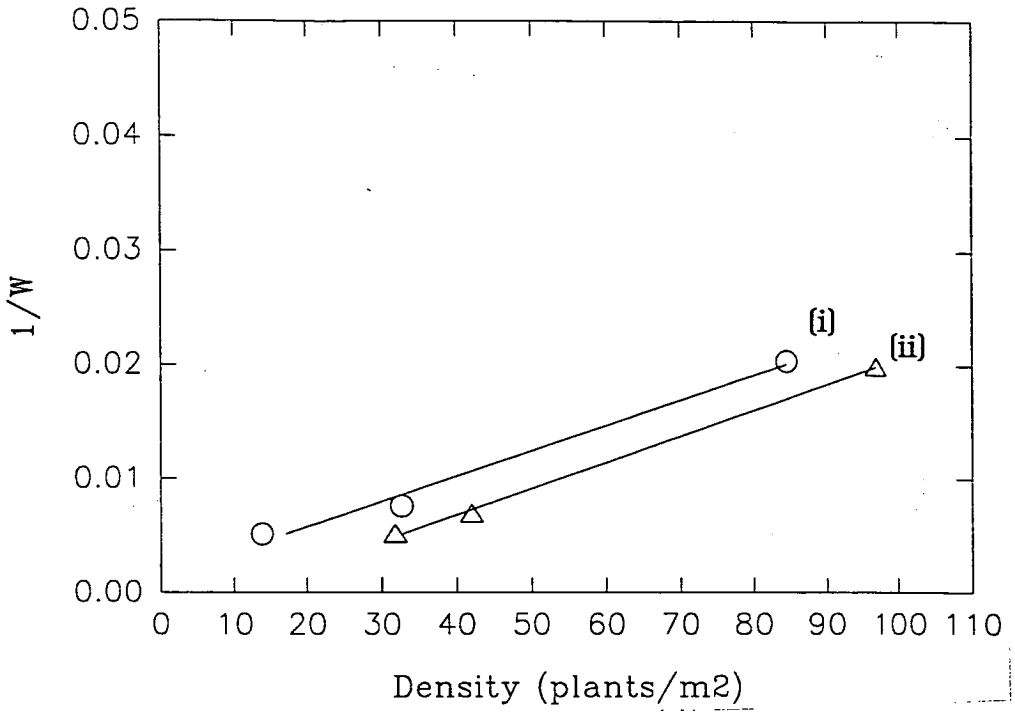

Fig 5.3. Relationships between reciprocal of weight per plant (1/W) approximately three weeks prior to harvest and density (plants/m^2) averaged over the three cultivars for Elliott (○) and Cressy(△). Fitted line equations are:

(i) $1/W = 0.0002$ Density + 0.001 $R^2 = 0.99$

(ii) $1/W = 0.0002$ Density - 0.002 $R^2 = 0.99$

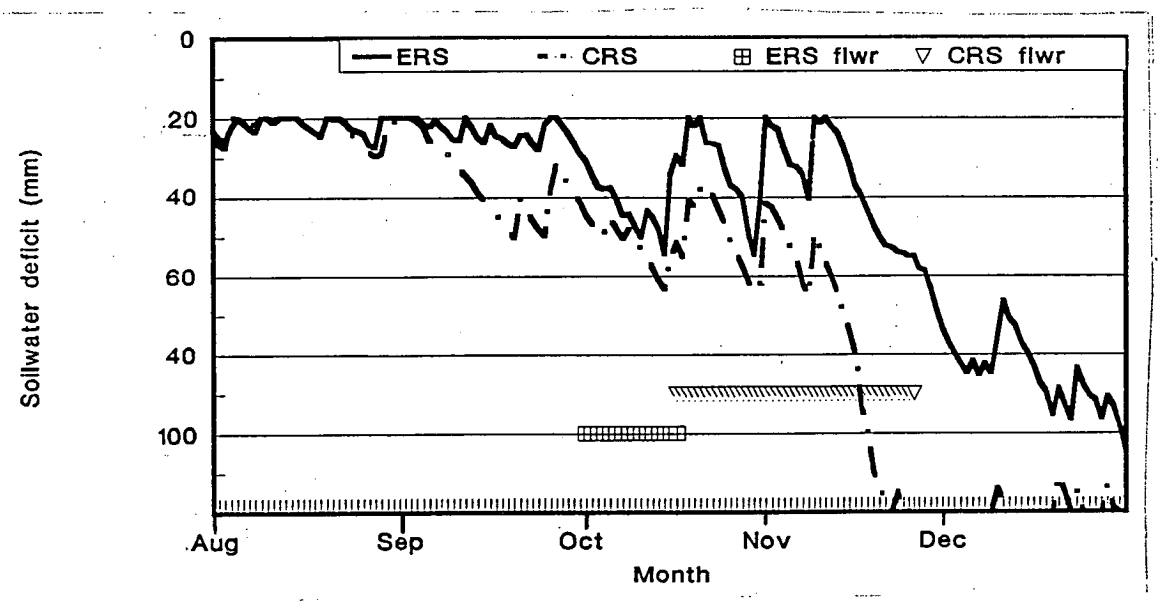

Fig 5.4. Estimated soil water deficit for Elliott and Cressy during the crop season. Period of flowering for each site overlaid on the soil water deficit estimates. Maturity of crops at both sites occurred in mid-January.

Soilwater deficit was estimated at Elliott and Cressy throughout the growing season (Fig 5.4). No moisture stress would have been likely at Elliott.

At Cressy, Fig 5.4 would indicate that soil water deficit should have been critical at the end of an extended flowering period. The continuation of flowering well after the crop should have been under stress indicated that external water sources must have been present. The experiment was located in an area with a shallow water table (Ian Bell, DPIF, personal communication). There was no indication of moisture stress during this latter period of flowering, and as with the previous experiment (Chapter Four), the plants at Cressy probably had access to groundwater late into the season. Access to this water supply, combined with the warm temperatures would also explain the extended flowering period at Cressy (Fig 5.4).

An examination of the development of leaf area index through ontogeny (Fig 5.6) shows larger leaf areas at Cressy, in accord with the larger plants. The relationship between leaf area and the ln% of transmitted light (Fig 5.5) indicates a difference between Elliott and Cressy. This difference may be due to leaf arrangement. Fig 5.5 indicates higher leaf extinction coefficient at Elliott suggesting a more horizontal arrangement of leaves. At Cressy, leaf areas were greater overall but the extinction coefficient was less- perhaps a greater competition for light has given a more erect leaf angle. The more erect angle on a larger L would be more efficient at photosynthesis with light spread over a greater area of leaf. With a sparse canopy (low L) a high extinction coefficient would allow more light to be intercepted but this may not be as efficiently converted to dry matter.

5.4.2. Density (x cultivar) effects

The total amount of drymatter produced by the lupins varied with changes in plant density (Fig 5.2). Due to an oversight, the weight of dry matter accumulated was not obtained at harvest. At Elliott, the accumulation of drymatter throughout growth was similar for Yandee and Geebung. 75A329 responded to an increase from 11 plants/m^2 (target 10 plants/m^2) to 20 plants/m^2 (target 40 plants/m^2) with a large jump in the amount of dry matter produced. An increase to 88 plants/m^2 (target 160 plants/m^2) resulted in a large increase in the amount of dry matter produced particularly early in the season. This indicates potential increased yield responses with higher plant densities for determinate cultivar types compared with indeterminate cultivars.

Increasing plant density resulted in higher leaf area production (Fig 5.6), but at the highest density areas were declining while they were still increasing on lower densities. Leaf senescence occurred earlier in the high density plots probably due to less branching. In the lower density plots at that time, the lupin plants were still branching (Fig 5.6) and leaf area was continuing to increase or had just started to decline.

Plotting the relationship between ln% transmitted light and leaf area index (L) throughout crop growth (Fig 5.7) demonstrated the importance of leaf angle in the leaf canopy and its effect on light extinction coefficients. A more horizontal leaf angle is characteristic of a high extinction coefficient, and a low density crop may have more horizontal leaves due to their wide spacing (Fig 5.8). The low density lupin plants had the highest extinction coefficient.

Grain yield/density curves (Fig 5.9) indicate an optimum density of 40 to 50 plants/m^2 for maximum grain yield at Cressy. As has already been established in chapter four, increasing plant density will increase the number of pods/m^2 up until the point of diminished

resources when competitive effects take over and no further increase is possible.

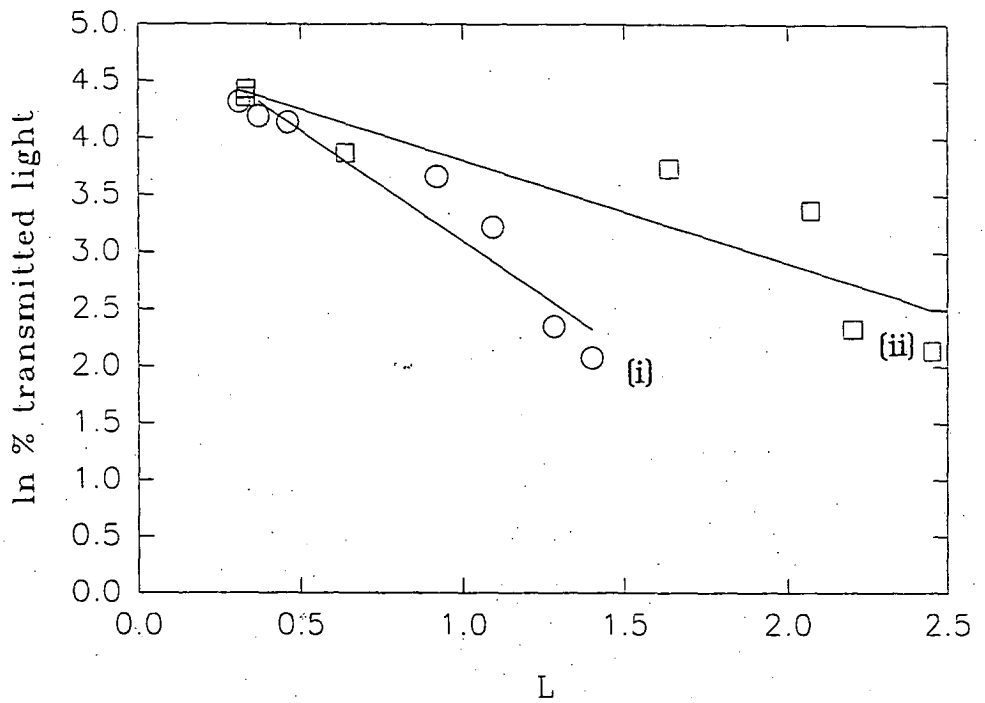

Fig 5.5. Relationships between ln% of transmitted light and leaf area index averaged over three cultivars and three densities for Elliott (○) and Cressy (□). Fitted lines are:
(i) ln% transm light = -2.90L + 5.541 $R^2 = 0.85$
(ii) ln% transm light = -0.89L + 4.702 $R^2 = 0.91$

The increased number of pods set on plants at lower density cannot continue to compensate for fewer plants.

The highest densities of both Geebung and 75A329 showed a slight decrease due to this competitive effect. The curves shown in Fig 5.9 have been plotted on three points only as this was the only data available. The computer generated spline curves showed the highest densities of each cultivar slightly decreasing in grain yield due to this competitive effect, but if the actual optimum was lower than $40m^2$, a plateau would represent the data at higher densities as well..

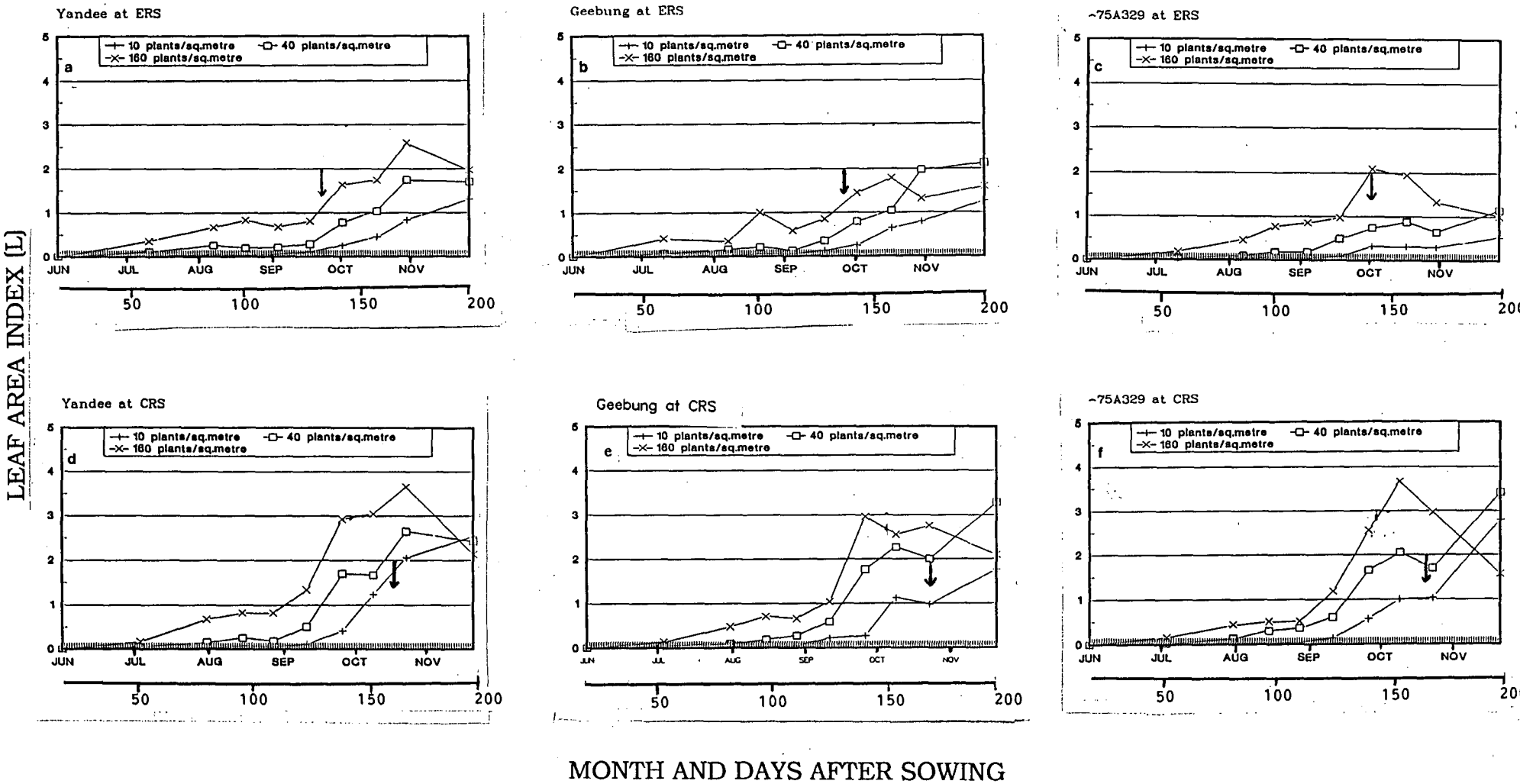

Fig 5.6. Leaf area index (L) plotted against time (month and days after sowing) for each cultivar and density at each site. Arrows mark commencement of flowering. ERS = Elliott, CRS = Cressy.

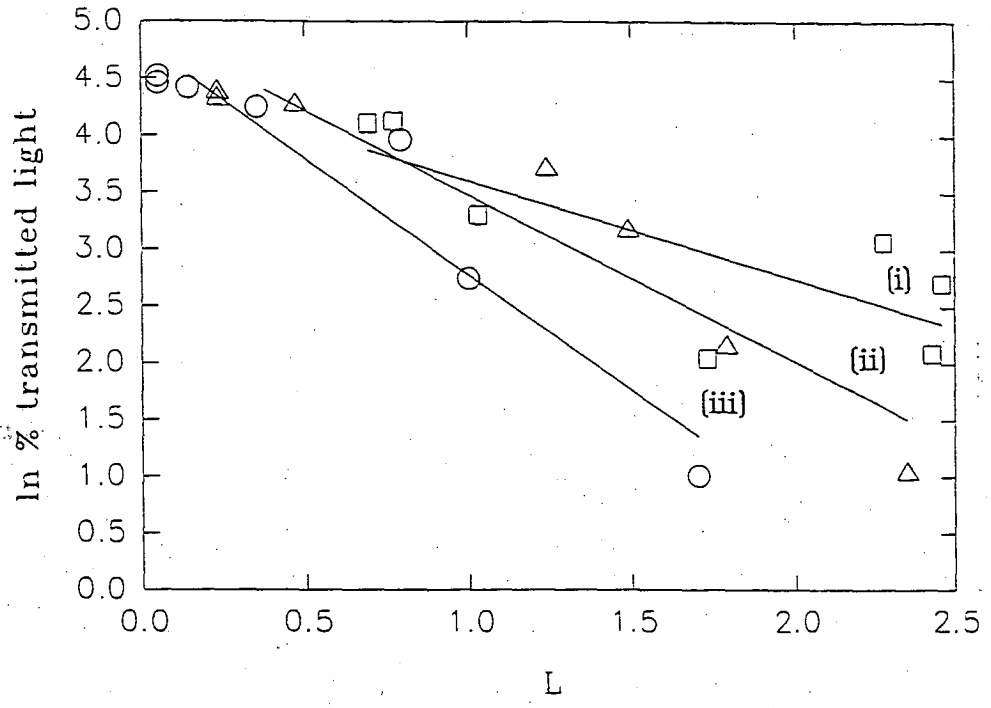

Fig 5.7. Relationships between ln% of transmitted light and leaf area index averaged over three cultivars and two sites for 160 (□), 40 (△), and 10 (○) plants/m2. The fitted lines are:

(i) ln% transmitted light = -1.10 L + 4.649 R^2 = 0.98

(ii) ln% transmitted light = -1.44 L + 4.648 R^2 = 0.92

(iii)ln% transmitted light = -2.03 L + 4.812 R^2 = 0.90

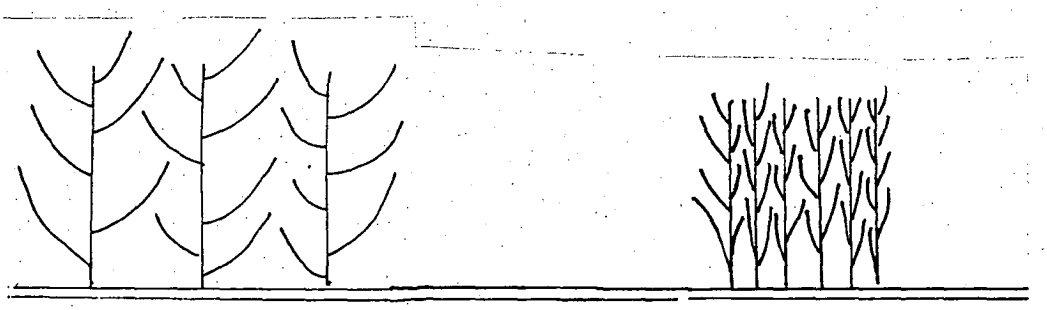

Fig 5.8. Diagrammatic representation of branching in low and high density crops. Low density crop results in branches leaning outwards to give leaves a more horizontal leaf angle (a). At higher densities, branches are held upright presenting a more vertical leaf angle (b).

Plate 5.1. Geebung lupins at a target density of 160 plants/m² at Elliott

Plate 5.2. Single Geebung lupin plant taken from a plot at target density 160 plants/m² (Plate 5.1). At the high plant density, each plants set fewer pods than plants at lower densities.

Plate 5.3. Geebung lupins at a target density of 40 plants/m² at Cressy.

Plate 5.4. Individual Geebung lupin plants taken from a plot at target density 40 plants/m² (Plate 5.3). These lupins are close to optimum density and have set a satisfactory number of pods on main stem and higher order branches.

Although yield components were not measured in this experiment, it has already been established in chapter four that similar yields can be produced with either high density resulting in few pods/plant (Plates 5.1 and 5.2) or low density resulting in more pods/plant (Plates 5.3 and 5.4).

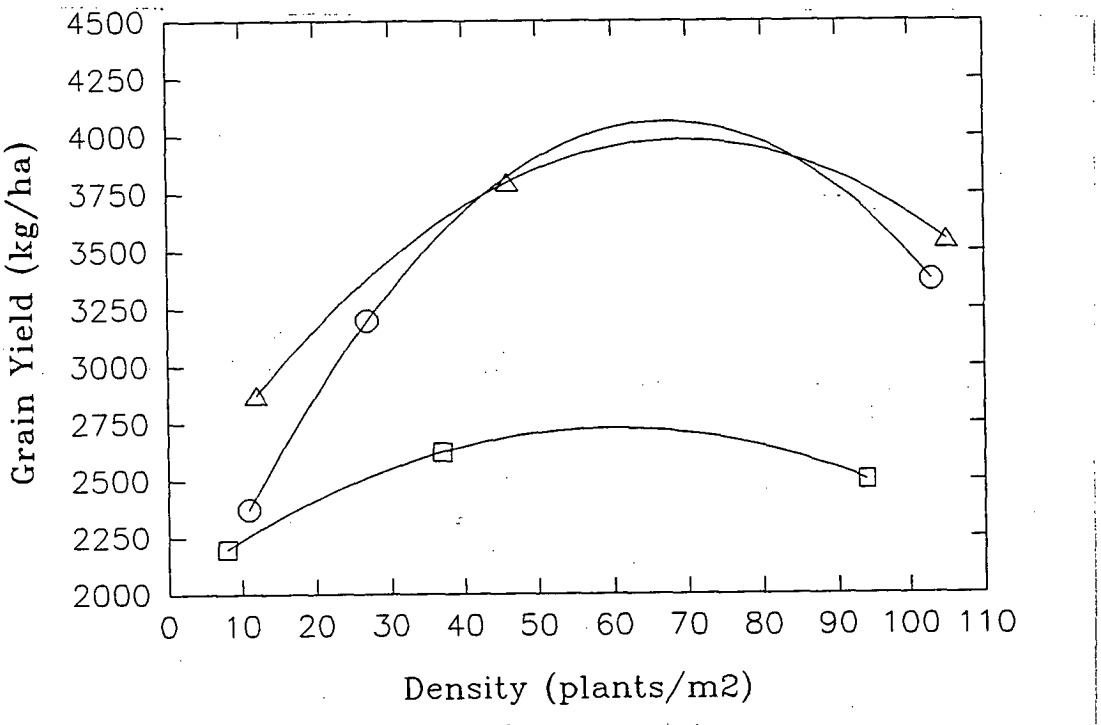

Fig 5.9. Relationship between grain yield at harvest (kg/ha) and actual lupin plant densities at Cressy for Yandee (○), Geebung (△), and 75A329 (□).

5.4.3. Cultivar effect

The indeterminate cultivars, Yandee and Geebung, appeared to yield more dry matter than the determinate 75A329 at Elliott and Cressy. (Fig 5.2). To explore these differences further, the data was averaged across the three density groups for each cultivar. At each site up until the commencement of flowering, all three cultivars were producing very similar quantities of dry matter (Figs 5.12 & 5.13). As flowering commenced and proceeded the amount of dry matter produced by the indeterminate and the determinate cultivars

diverged. At Cressy, 75A329 dry matter production decreased sharply while Yandee and Geebung continued producing dry matter, probably a result of their ability to keep branching under favourable growing conditions, in this case groundwater access. 75A329 however had reached its maximum growth potential. At Elliott, 72A329 followed a similar pattern to the other cultivars i.e. a decline from peak dry matter as pods matured but at a much lower level.

Leaf Area Index data (Fig 5.6) was also examined in a similar way to cultivar dry matter production (Fig 5.10 & 11). Leaf Area Index development followed a similar pattern to the production of dry matter with divergence in values occurring at the commencement of flowering. 75A329 tended to have a lower L and this decreased sooner, particularly at Elliott, probably due to senescence brought on by the cultivar reaching its maximum growth potential. However, the similarity between the canopy characteristics of all cultivars throughout much of the growth period (prior to flowering) was highlighted when ln% transmitted light was plotted against leaf area index for each cultivar (Fig 5.14).

Apart from some cultivar differences in dry matter production through ontogeny, the most significant difference was between grain yields (Fig 5.9). Yandee and Geebung yielded more grain than 75A329. This appeared due to the indeterminate characteristic of Yandee and Geebung; these cultivars were able to fully utilise the favourable growing conditions present late in the season and continued flowering and setting pods on higher order branches. 75A329 was able to increase in height and set a few more pods on the main stem but could not take full advantage of these conditions due to its reduced branching characteristic.

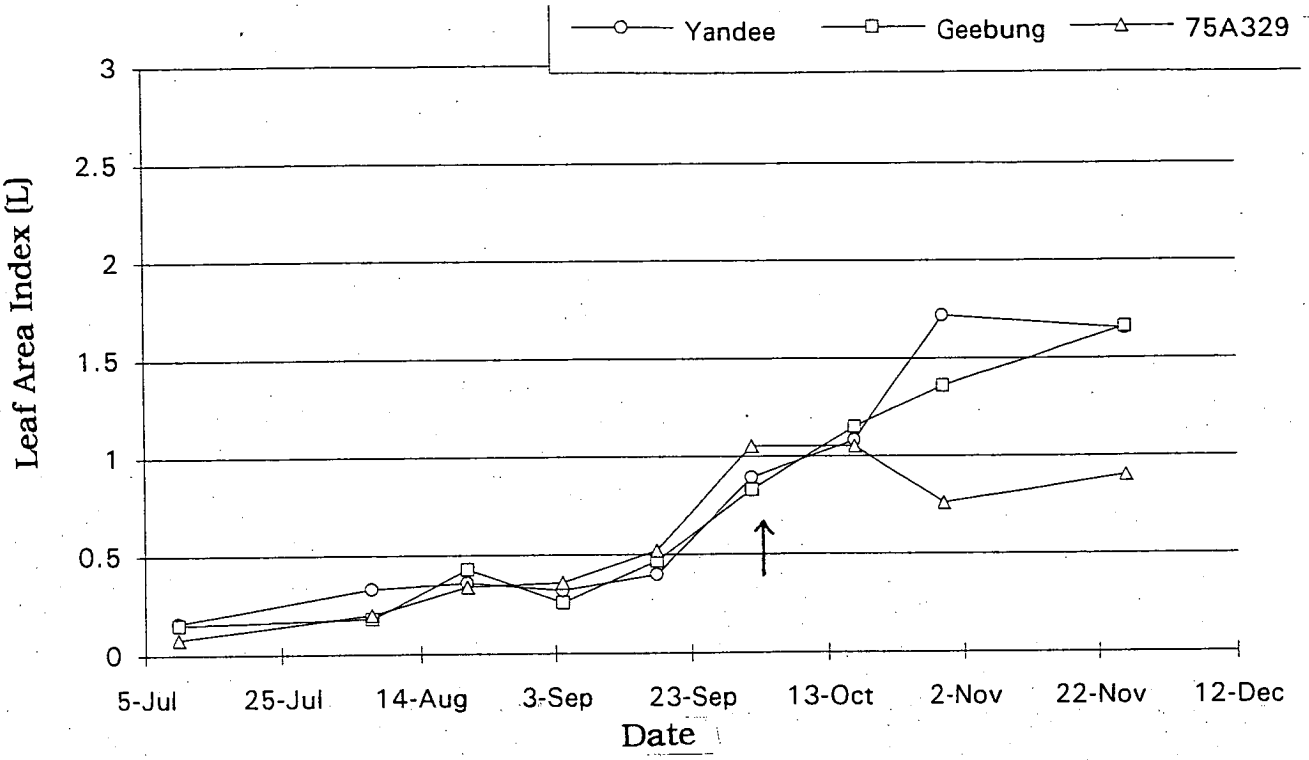

Fig 5.10. Leaf area index (L) plotted against date for each cultivar averaged over the three plant densities at Elliott. The arrow marks the commencement of flowering

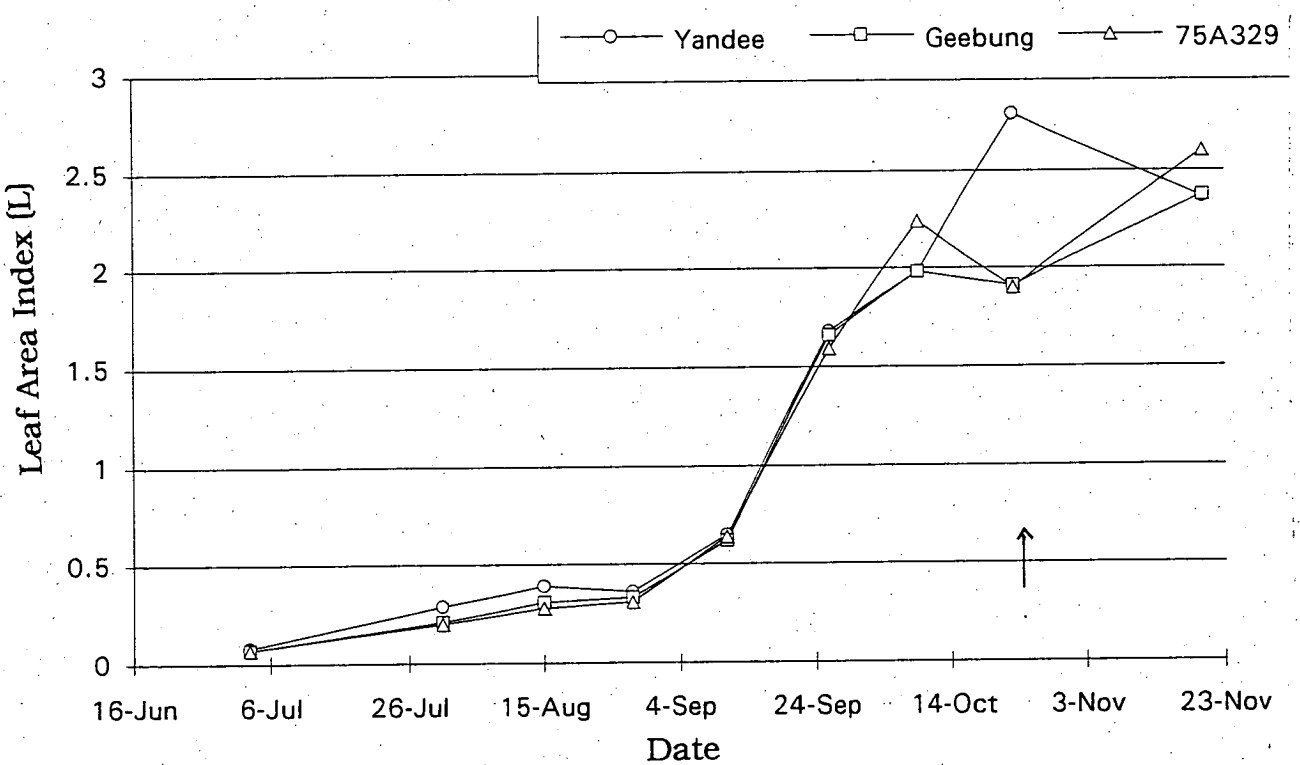

Fig 5.11. Leaf area index (L) plotted against date for each cultivar averaged over the three plant densities at Cressy. The arrow marks the commencement of flowering

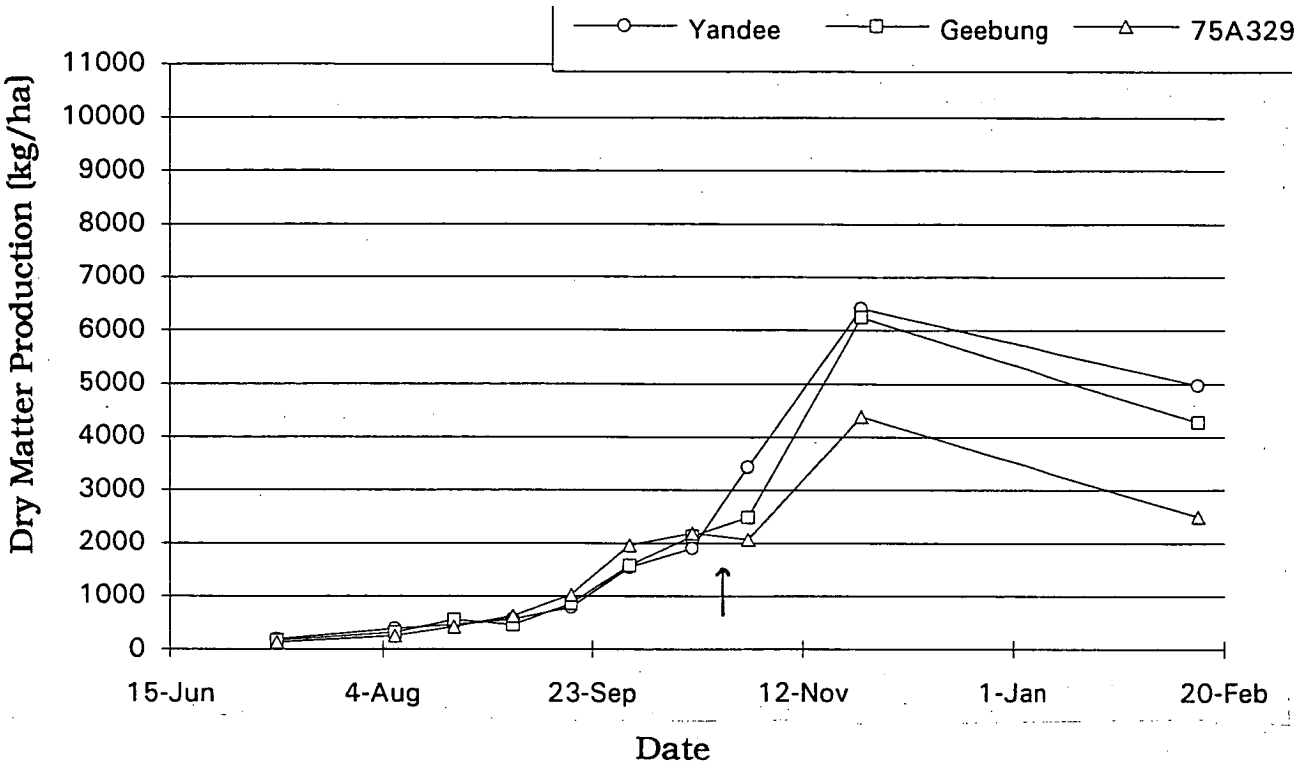

Fig 5.12. Dry matter production (kg/ha) plotted against date for each cultivar averaged over the three plant densities at Elliott. The arrow marks the commencement of flowering.

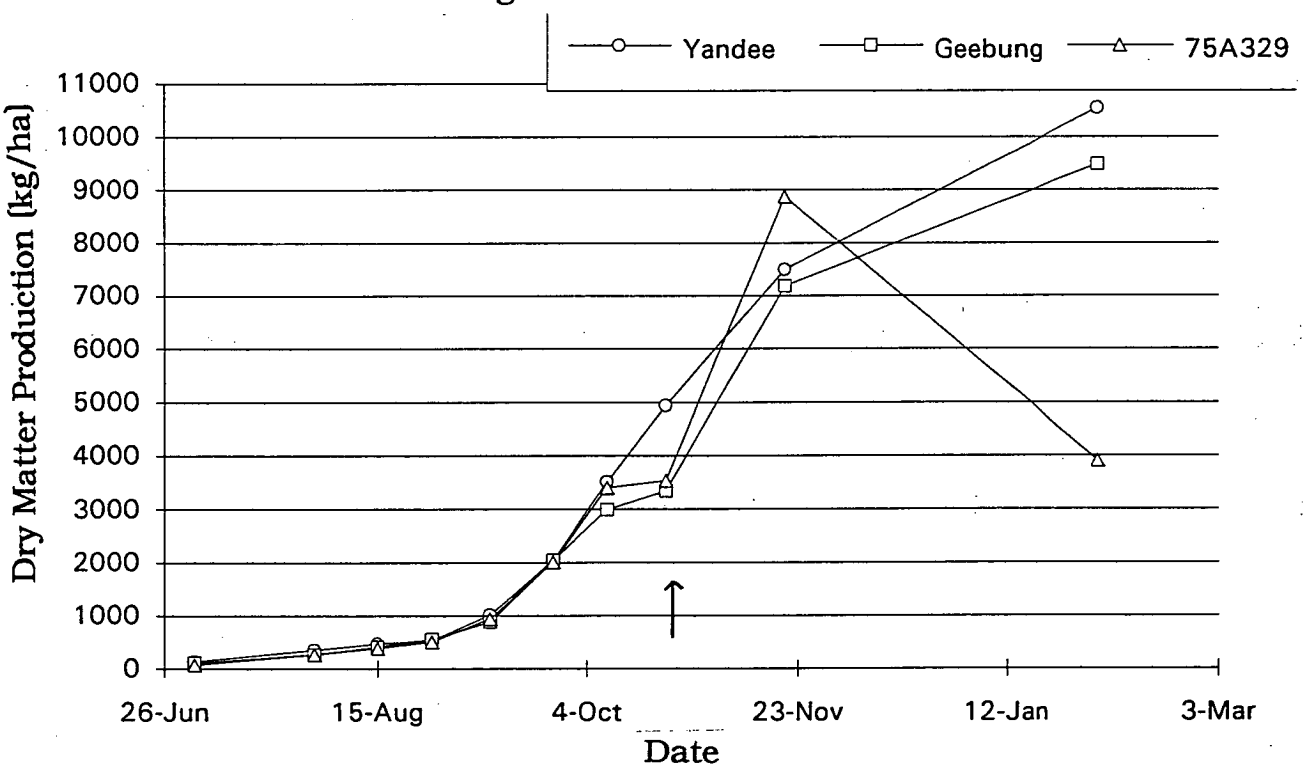

Fig 5.13. Dry matter production (kg/ha) plotted against date for each cultivar averaged over the three plant densities at Cressy. The arrow marks the commencement of flowering.

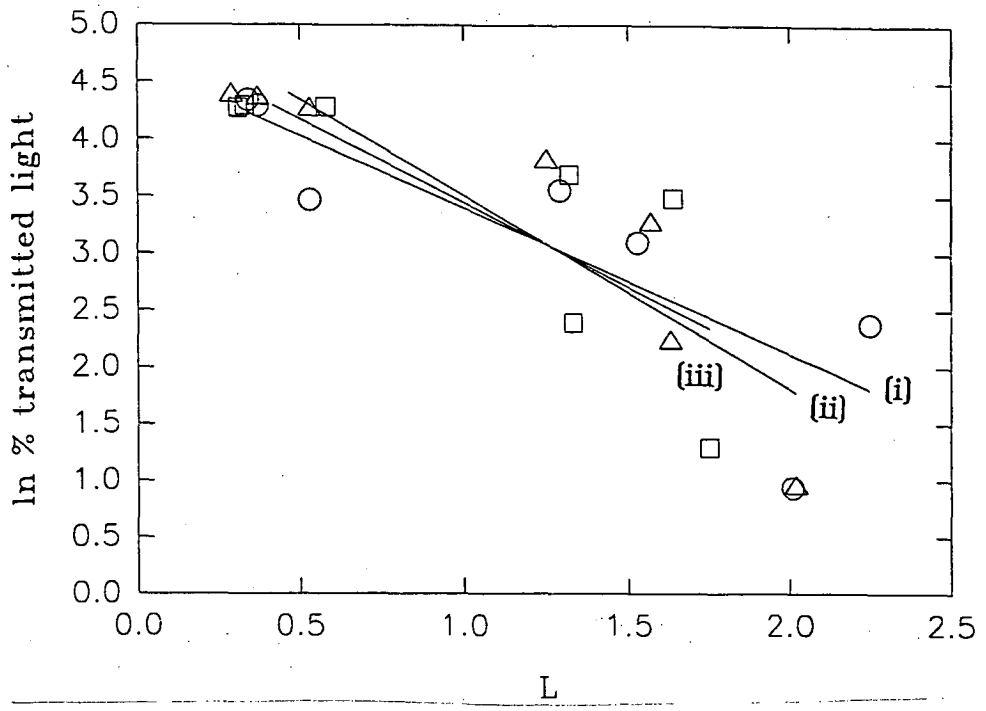

Fig 5.14. Relationships between ln% transmitted light and leaf area index averaged over both sites and three densities for (i) Yandee (o), (ii) Geebung (□), and (iii) 75A329 (△). Fitted lines are:

(i) ln% transm. light = -1.268 L + 4.66 R^2 = 0.85
(ii) ln% transm. light = -1.685 L + 5.19 R^2 = 0.90
(iii)ln% transm. light = -1.463 l + 4.90 R^2 = 0.79

The characteristics of each cultivar group highlight potential disadvantages of determinate cultivar types in possible long season environments such as Tasmania.

5.4.4. Incident radiation and crop growth rate

The aim of measuring continuous radiation was to relate the production of dry matter and leaf area at each site and for each cultivar to the amount of energy received from radiation. However, the malfunction of the instrument at one site and its destruction by

livestock at the other resulted in insufficient reliable data to examine this relationship.

5.4.5. Comparison of Season 1989 (Chapter Four) with Season 1990 (Chapter Five).

This section briefly compares results from the previous two experiments (1989 and 1990). These will be expanded upon in the Discussion in Chapter Six.

Temperatures at both sites over both seasons (Figs 4.2 c and 5.1 c) were above average during December but virtually the same between seasons. Rainfall during the flowering period was lower at both sites in 1990 compared with 1989. (Figs 4.2 a and 5.1 a). These seasonal comparisons are made against the long term weather data for each site in Appendix D. Due to an earlier planting in 1990, both sites accumulated more day degrees before flowering than in 1989 (Fig 4.1 d and Fig 5.1 d).

Dry matter production by Yandee and Geebung was very similar between seasons as was the development of leaf area index. 75A329 showed improvements in drymatter production, leaf area index, and subsequently grain yield in 1990 compared with 1989.

Overall it seems that the second season's planting was an improvement in terms of drymatter accumulated, leaf area development, and grain yield. Climatic differences were not large, but the 1990 experiment was sown approximately four weeks earlier. The crops at each site had more time to develop, and hence a higher yield potential resulted. In New Zealand, Withers *et al.* (1974) demonstrated a linear reduction in yield with sowings from April through to October. The grain yield results in the experiments in Chapters Four and Five confirm these findings.

Comparing thermal time taken to reach flowering in each season (Table 5.3) indicated that the differences between seasons were much greater than the differences between sites. This inferred that flowering was nearly independent of sowing time, further indicating vernalisation and/or long day as floral initiators.

Table 5.3. Accumulated number of days and thermal time averaged for the three cultivars from sowing until 50% flowering was reached for both sites over the two seasons. (Additional relevant data noted below table).

Season	Site	Days	Day Degrees
1989	Elliott	120	1154
	Cressy	140	1059
1990	Elliott	150	1361
	Cressy	157	1128

Note:
(Averaged for three cultivars for simple site and season comparison)

	Sowing dates	Approx. 50% Flowering dates
1989 Elliott	13th June	11th October
1989 Cressy	1st June	19th October
1990 Elliott	15th May	12th October
1990 Cressy	8th May	12th October

5.5. Conclusions

Some of the different growth responses between lupins grown at Elliott and Cressy detailed in Chapter Four have been confirmed in this experiment. Although final dry matter yield and grain yield are unavailable for Elliott, the growth responses throughout the season compared favourably with 1989. At Cressy, grain yields in 1990 were

higher than in 1989. The variation in planting dates between seasons would explain this. A temperate crop such as lupins generally benefits from a longer growing season.

Moisture stress could be a potential problem in lower rainfall environments such as Cressy in the absence of unusual benefitting factors such as groundwater access. Normally, the season would have been cut short, and the optimum grain yields would not have been reached.

Elliott is consistently warmer during the winter, while Cressy is warmer than Elliott during the summer. The conditions at Elliott thus favour more rapid early growth. There appears to be an advantage in sowing early to maximise growth time for the lupin crop. The earlier sown plants in 1990 flowered at about the same time as those planted four weeks later in 1989. This indicates at least a partial photoperiod or vernalization response in floral initiation.

It seems maximising plant dry weight will result in higher grain yields. Sowing earlier allowed for more crop growth and particularly seemed to benefit the determinate cultivar, 75A329. This cultivar can only increase its yield through pre-flowering growth. Once podset has been achieved, it can no longer take advantage of extended favourable seasons unless continued flowering on the mainstem is possible. Its reduced branching characteristic restricts pod set to the main stem and first few branches and as Porter (1982) indicated, although all lupin flowers had similar pod set abilities, they were inhibited by pods setting below them. As the gap between the stage of flower development and pod development increased, later forming flowers were more likely to abort on the same inflorescences, as earlier newly formed pods will compete more strongly for the photosynthate products.

Plate 5.5. Yandee lupin plants at growth stage A4 (as detailed in Appendix B).

Plate 5.6. Yandee lupin plants at growth stage A7 (as detailed in Appendix B).

To draw some recommendations for lupin cultivars from the evidence presented here, in Tasmania lupin plants should be sown in May rather than June to maximise dry matter accumulation and grain yield. The indeterminate cultivars, Yandee and Geebung should be used in preference to the determinate type 75A329. An improved pod set and/or high plant density would be required to gain a yield advantage from this type. The growth curve for lupins in Tasmania compares favourably to that described by Greenwood *et al.* (1975). Typical lupin growth consists of a period of slow dry matter accumulation, more extended than in other crops (Plate 5.5 and 5.6), up until flowering when branching begins. Here the curve differs slightly (but significantly) from Greenwood's description. In Tasmania, the period of rapid growth is likely to be extended due to favourable environmental conditions. This extension is important in maximising grain yields. The experiments did show the start of the plateau phase at the completion of pod set, and the decline in leaf area index as plants matured and leaves senesced. Optimum plant densities (approximately 40 plants/m^2), indeterminate cultivars, and early sowing are likely to maximise lupin grain yield production in Tasmania. It should be mentioned that the determinate line 75A329 is an early stage in determinate cultivar breeding. As yet there are no determinate cultivars released as predicted increases in yield for this type of cultivar have not been realised. In the long term, an ideotype as described by Donald and Hamblin (1983) may be required, i.e. shorter, more erect leaves, reduced branching, higher harvest index, and higher yield potential when sown at high density.

CHAPTER SIX

INTEGRATION AND EXAMINATION OF LUPIN CROP GROWTH, DEVELOPMENT, AND YIELD DATA COLLECTED AT ELLIOTT AND CRESSY, TASMANIA (1989 AND 1990)

6.1. Introduction

The first part of this study established that lupins can be cultivated at high and low rainfall sites in Tasmania with a high degree of success (Chapter 3). Further studies (Chapters 4 and 5) were conducted to provide detailed data about factors that influenced the lupin crop's growth and development. To make best use of this data, it is desirable to incorporate it into a form useful for predicting site suitability and potential grain yield. An empirical model was planned (Fig 6.1) that would assess site suitability by predicting potential lupin crop grain yields based on several internal and external factors. Although it was acknowledged that such a model would not approach the complexity of some of those listed in the literature review (Weir *et al.* 1984, Stapper and Murray, 1986, Elliott and Loss,1989), it was hoped a set of relationships could be determined that would provide a useful indication of crop performance, and that could provide a basic model for further development by future researchers.

Factors intended for inclusion in the model from Chapters 4 and 5 are examined in this chapter and their effects summarised. Modelling of specific relationships is attempted and where possible, these relationships linked together to form the model.

The final model produced in this chapter is only intended to summarise the data collected in 1989 and 1990. However it is a step towards a predictive model suitable for cropping site selection.

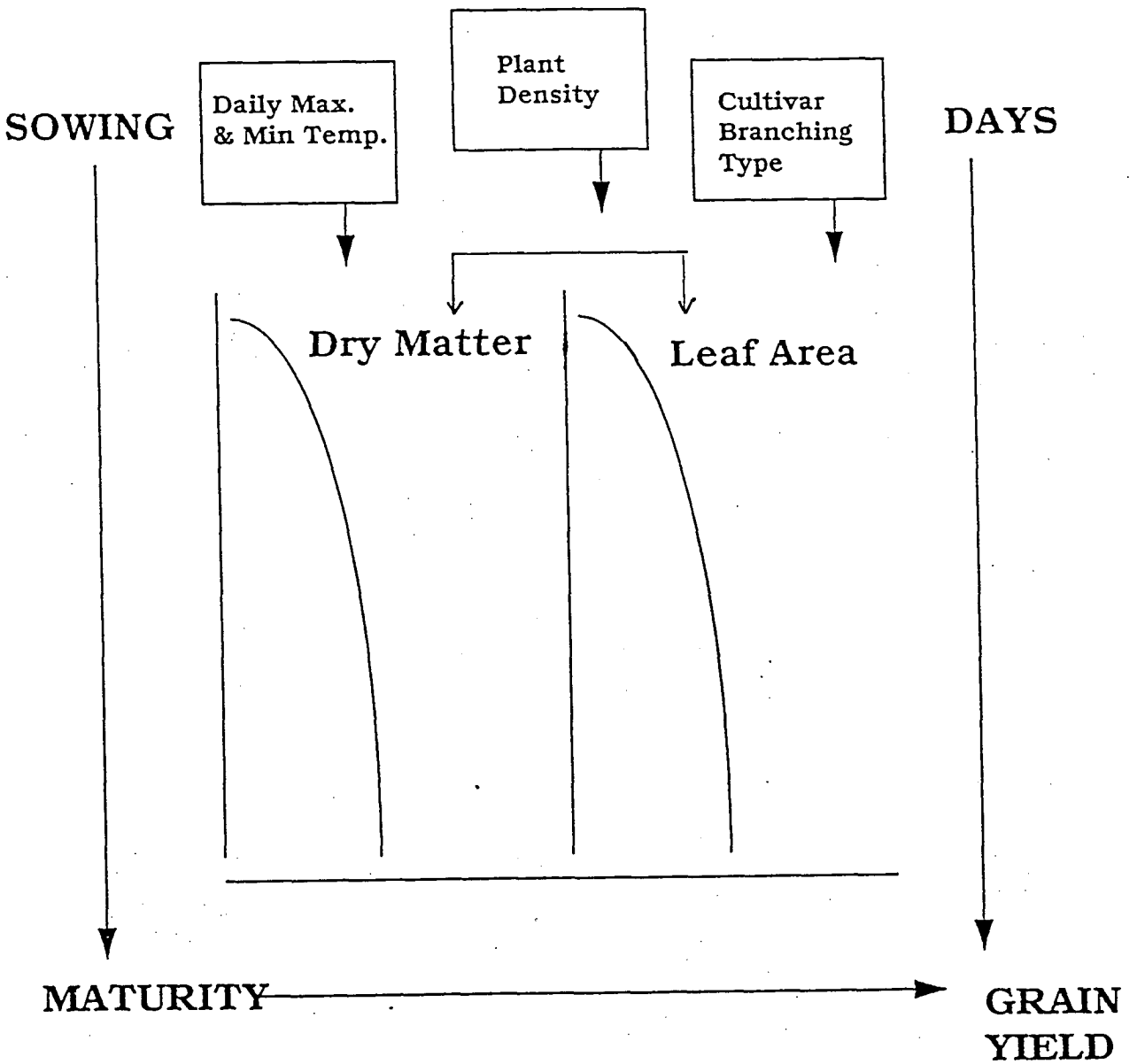

Fig 6.1. Schematic diagram of the proposed empirical model. Main input data are temperature, cultivar, branching type, and plant density. Grain yield is related directly to final total dry matter production. Schematic diagram layout after Weir *et al.* (1984).

6.2. Aim

(i) To provide a descriptive summary of lupin crop growth, development, and yield data collected over the previous two seasons using both internal (leaf area, plant density, crop dry weight) and external factors (temperature, radiation, cultivar, and branch type).

(ii) To integrate this data into sub-models in the form of regression equations.

(iii) To combine the sub-models into one overall empirical model that describes the growth of lupins at Elliott and Cressy in 1989 and 1990.

6.3. Materials and Methods

In order to assess the suitability of a site for growing lupins, it is necessary to know how external factors such as temperature and radiation vary over the season at that site. The assessment of site suitability would be based on the crop's growth, development, and ultimately the yield of grain that can be produced at that site. In the study detailed in preceding chapters, it was essential to determine the relationships between the external and internal factors affecting crop growth and development (leaf area development, plant density, dry weight accumulated). Relating these internal factors to grain yield via mathematical equations could enable highly correlated relationships to be incorporated into a simple empirical model that could be used to

assess site suitability for lupins based ultimately on predicted potential grain yields.

The proposed empirical model is illustrated in Fig 6.1. Based on data collected in 1989 and 1990, the relationships between the factors detailed in the diagram were examined individually and their suitability determined for inclusion in the empirical model. The statistical package MINITAB(R) was used for all statistical analysis. Sigma-plot(R) was used for most of the plots and simple regression analysis. As each relationship was examined, problems encountered in collecting or using the data were detailed. As a guide, regression equations with $R^2>0.70$ were used; relationships with a lower R^2 were not included in the final model in an effort to maximise model accuracy.

The choice of equations to use in the empirical model was also governed by some practical considerations. Separate cultivar relationships were developed although it is most unlikely that a determinate cultivar would be planted in Tasmania. Where separate site equations are produced, equations relating to Elliott were chosen. The unusual soil moisture conditions at Cressy (discussed previously) may make it an atypical site.

6.4. Results and Discussion

6.4.1. Effect of external factors on crop growth

6.4.1.1. Thermal time and leaf area development

Development of substantial leaf area in any crop is essential for optimising light interception and photosynthesis, and maximising eventual crop yield. The relationship between thermal time and development of leaf area was studied so as to provide the empirical model with a useful external/internal factor relationship. In order to

minimise seasonal effects on this relationship, data from both seasons were plotted as single plots for site, cultivar and density (Fig 6.2). Simple linear regression accounted for satisfactory levels of variation in most cases i.e.R^2 >0.70%. These regression relationships are listed in Table 6.1.

Immediately obvious was a site effect. At Elliott more day degrees were needed to accumulate to reach the same L as at Cressy. L development at Cressy was more rapid and higher L's were reached. Perhaps this was due to the favourable soil moisture conditions at Cressy. Cultivar effects were also evident with 75A 329 showing more dissimilar relationships than the two indeterminate cultivars. Density effects were expected and confirmed by the data. Lower density plots took longer to increase their L and finished with low Ls. The higher the density the more rapid the development of L, and the higher the L that was finally reached. The effect of plant density on L was important. It emphasised the importance of optimum plant densities to achieve sufficient leaf area to maximise crop yield. It also suggested that optimum plant densities can vary according to potential thermal time accumulation at a site. Cooler areas may require higher plant densities than warmer locations. This of course assumes ample supply of other essential factors such as water and nutrients. The regression equations relating these two variables are listed (Table 6.1).

6.4.1.2. Radiation transmission and leaf area development

The relationship between the natural log of the percentage of radiation transmitted through the canopy of the lupin plants was related to the development of leaf area index over time in both 1989 and 1990. In the discussion of these relationships in both experiments (Chapters 4 and 5), it was found that site and cultivar had very little effect on this

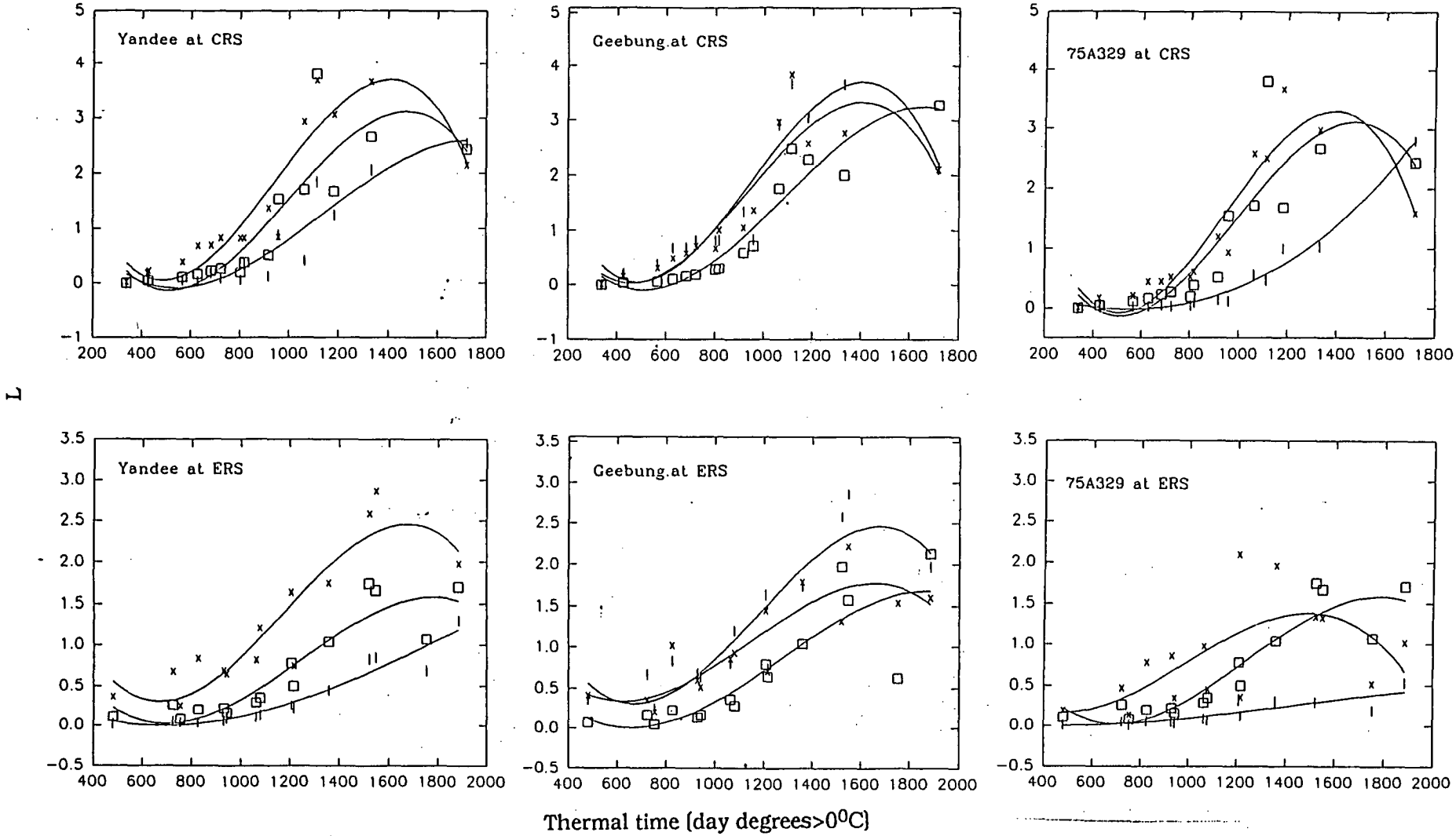

Fig 6.2. Leaf area index (L) plotted against thermal time (day degrees) for each cultivar and density at each site. Plots are the combined data collected in 1989 and 1990. Regression equations listed in Table 6.1. ERS = Elliott, CRS = Cressy.

Table 6.1 Polynomial equations that show the relationship between development of leaf area (L) and thermal time (dd).

Site	Cultivar	Target plant/m^2	Equation	R^2
ERS	Yandee	10	$L = -(4\times10^{-10})dd^3 + (197\times10^{-8})dd^2 - 0.002dd + 0.691$	0.96
		40	$L = -(24\times10^{-10})dd^3 + (899\times10^{-8})dd^2 - 0.009dd + 2.73$	0.93
		160	$L = -(42\times10^{-10})dd^3 + (1483\times10^{-8})dd^2 - 0.014dd + 4.42$	0.92
	Geebung	10	$L = -(42\times10^{-10})dd^3 + (1483\times10^{-8})dd^2 - 0.014dd + 4.42$	0.92
		40	$L = -(19\times10^{-10})dd^3 + (7171\times10^{-8})dd^2 - 0.007dd + 2.02$	0.86
		160	$L = -(26\times10^{-10})dd^3 + (8899\times10^{-8})dd^2 - 0.008dd + 2.52$	0.87
	75A329	10	$L = -(2\times10^{-10})dd^3 + (6413\times10^{-8})dd^2 - 0.005dd + 0.111$	0.85
		40	$L = -(24\times10^{-10})dd^3 + (8990\times10^{-8})dd^2 - 0.009dd + 2.73$	0.93
		160	$L = -(24\times10^{-10})dd^3 + (7118\times10^{-8})dd^2 - 0.005dd + 1.30$	0.65
CRS	Yandee	10	$L = -(32\times10^{-10})dd^3 + (1076\times10^{-8})dd^2 - 0.008dd + 2.03$	0.94
		40	$L = -(72\times10^{-10})dd^3 + (2154\times10^{-8})dd^2 - 0.016dd + 3.55$	0.89
		160	$L = -(93\times10^{-10})dd^3 + (2638\times10^{-8})dd^2 - 0.019dd + 4.15$	0.94
	Geebung	10	$L = -(93\times10^{-10})dd^3 + (2639\times10^{-8})dd^2 - 0.019dd + 4.15$	0.94
		40	$L = -(44\times10^{-10})dd^3 + (1441\times10^{-8})dd^2 - 0.011dd + 2.46$	0.96
		160	$L = -(77\times10^{-10})dd^3 + (2145\times10^{-8})dd^2 - 0.015dd + 3.03$	0.92
	75A329	10	$L = (4\times10^{-10})dd^3 + (9379\times10^{-8})dd^2 - 0.001dd + 0.390$	0.99
		40	$L = -(72\times10^{-10})dd^3 + (2154\times10^{-8})dd^2 - 0.016dd + 3.55$	0.89
		160	$L = -(97\times10^{-10})dd^3 + (2774\times10^{-8})dd^2 - 0.021dd + 4.52$	0.95

relationship (Figs 4.7 and 5.6). Differences were noted between the plant densities. A comparison of equations averaged over both sites and each cultivar for each season (Table 6.2) indicates very little seasonal effect on this relationship.

Plant density affects the leaf angle within a crop thus influencing the amount of radiation the leaf canopy intercepts with a specific leaf area. A low density crop will have more horizontal leaves as the plant's branches to spread out to fill in the gaps between plants, consequently a high extinction coefficient is characteristic of this more horizontal leaf angle

As there is very little seasonal effect on this relationship the equations for the 1989 season were chosen for use in the empirical model. Separate equations for each density (representing low, medium and high) have been maintained. These equations have been selected to be linked with the relationships developed in section 6.4.1.1.

6.4.1.3. Intercepted radiation and accumulation of crop dry matter

The measurement of the crops interception of radiation at each harvest in both experiments enabled the relationship between the crops total dry weight and its corresponding interception of light to be examined (Fig 6.3). Although data was plotted separately for site, density, and cultivar it is obvious how similar this relationship is for each.

Table 6.2 Regression equations obtained by averaging both sites and cultivars for each plant density presented for each season.

Year	Target plant/m^2	Actual plant/m^2	Equation	R^2
1989	10	9	ln%TR = -1.78L + 4.7	0.90
	40	19	ln%TR = -1.44L + 4.7	0.92
	160	82	ln%TR = -1.10L + 4.7	0.98
1990	10	8	ln%TR = -2.03L + 4.8	0.90
	40	27	ln%TR = -1.44L + 4.6	0.91
	160	103	ln%TR = -1.10L + 4.6	0.96

ln%TR = natural logarithm of % transmitted radiation
L = leaf area index

Increasing leaf area results in more light being intercepted and increase in total dry matter accumulated because of plant growth. However

even within one target density, similar radiation interception values were obtained for extreme total crop dry matter. This can be explained

Table 6.3 Second order regression relationships that show the relationship between development of total dry matter production (kg/ha) and intercepted radiation (%) across crop growth period for 1989 and 1990 (combined).

Site	Cultivar	Target psm	Equation	R^2
ERS	Yandee	10	DM = 19.97 + 15.39(IR) + 0.093(IR)^2	0.96
		40	DM = 109.98 - 2.56(IR) + 0.39(IR)^2	0.95
		160	DM = 636.90 - 50.66(IR) + 0.98(IR)^2	0.91
	Geebung	10	DM = 56.39 + 5.47(IR) + 0.12(IR)^2	0.79
		40	DM = 24.69 + 12.31(IR) + 0.17(IR)^2	0.94
		160	DM = 173.52 + 21.48(IR) + 0.19(IR)^2	0.89
	75A329	10	DM = 63.18 + 13.69(IR) - 0.05(IR)^2	0.81
		40	DM = -115.46 + 26.05(IR) - 0.06(IR)^2	0.89
		160	DM = 244.95 - 6.27(IR) + 0.49(IR)^2	0.92
CRS	Yandee	10	DM = 8.06 + 34.45(IR) + 0.02(IR)^2	0.87
		40	DM = 194.91 - 10.79(IR) + 0.50(IR)^2	0.87
		160	DM = 374.26 - 32.11(IR) + 0.72(IR)^2	0.68
	Geebung	10	DM = -65.14 + 30.20(IR) - 0.19(IR)^2	0.74
		40	DM = 47.63 + 10.72(IR) + 0.25(IR)^2	0.91
		160	DM = 264.35 - 12.75(IR) + 0.55(IR)^2	0.84
	75A329	10	DM = 48.99 + 16.84(IR) + 0.03(IR)^2	0.79
		40	DM = -18.06 + 48.41(IR) - 0.32(IR)^2	0.64
		160	DM = 167.27 - 10.54(IR) + 0.62(IR)^2	0.85

DM = Total crop dry matter (kg/ha), IR = Intercepted radiation (%)

psm = plants/m^2

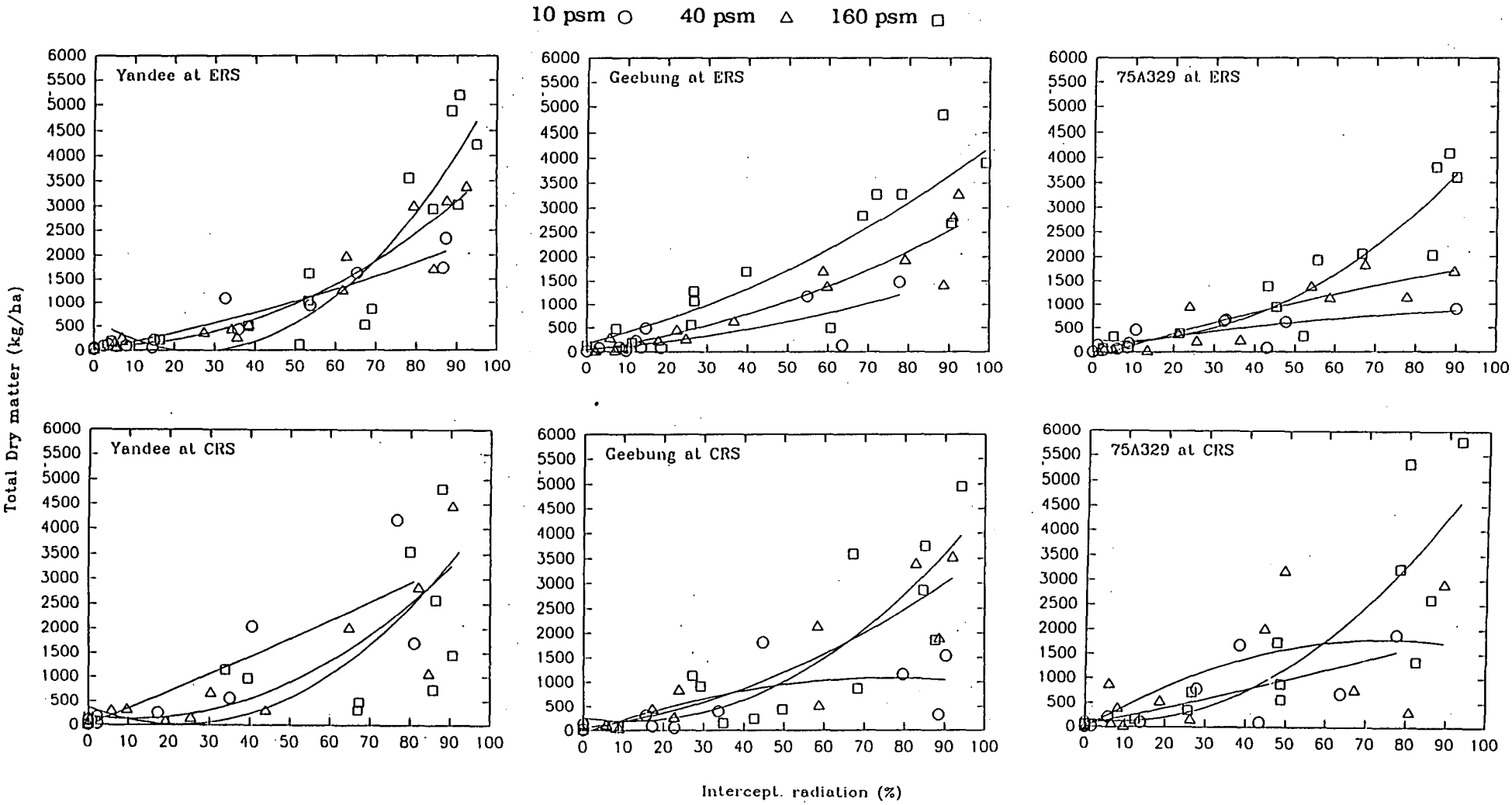

Fig 6.3 Total crop dry matter (kg/ha) plotted against intercepted radiation (%) for each cultivar and density at each site. Regression equations shown in Table 6.3. ERS = Elliott, CRS = Cressy.

by two factors. First, there was some variation in the actual plant densities in each season, thus 1989 target density of 10 plants/m^2 was not the same as the 1990 target density of 10 plants/m^2, although they were in a similar size group. The difference also indicates that a lower density crop may be able to compensate for its lack of leaf canopy due to its leaf angle being more horizontal (this has been fully discussed in section 5.4.2 Density effect and 6.4.1.2 Radiation transmission and leaf area development). The percentage of intercepted radiation was used rather than the quantity (MJ) of intercepted radiation, because quantitative radiation measurements were not collected during crop growth.

The plotted data demonstrated the very slow accumulation of dry matter followed by the rapid growth period from flowering to maturity (Fig 6.3).

The regressions for each of these plots (Table 6.3) demonstrate a good accountability for data variance in most cases. However, it should be noted that both axes are recording cumulative rather than incremental increases that may contribute to the overall high R^2 values. Some poor correlations could be attributed to difficulties encountered in data collection. For example, interference due to excess weed growth was encountered when collecting radiation data in the 75A329 treatments. This cultivar was very slow to form a canopy, and was highly prone to competitive weed growth.

6.4.1.4. Plant density and mature plant dry weight

There were both cultivar and site differences affecting this relationship in 1989 and only site differences affecting it in 1990. Equations for data collected in 1989 are in Table 6.4.

Table 6.4 The relationships between the inverse individual plant weights at harvest(1/W) and the density of plants (den) showing cultivar differences. (1989 data only).

Year	Cultivar	Equation	R^2
1989	Yandee	1/W = 0.002den + 0.037	0.99
	Geebung	1/W = 0.002den + 0.052	0.98
	75A329	1/W = 0.003den + 0.090	0.98

Site differences were consistent across both seasons with Cressy producing larger plants than Elliott. An explanation for this has already been provided in Chapters 4 and 5, and relates to likely crop access to groundwater at Cressy.

Strong R^2 values indicate equations averaged over both sites for each cultivar were suitable for inclusion in the summary model. Despite high R^2 values detected for the site specific equations (Table 6.3), these equations were not included in the model due to the unusual influence of probable access to groundwater at Cressy.

Table 6.5 The relationships between inverse individual plant weights at harvest (1/W) and the density of plants (den) showing site differences.

Year	Cultivar	Equation	R^2
1989	Elliott	1/W = 0.001den + 0.056	0.98
	Cressy	1/W = 0.001den + 0.001	0.99
1990	Elliott	1/W = 0.002den + 0.001	0.99
	Cressy	1/W = 0.002den - 0.020	0.99

6.4.1.5 Plant density and lupin grain yield production

This relationship was considered important as plant density data can be easily collected. It was hoped that some indication of grain yield could be obtained from simple plant counts. Yield/plant density curves were plotted at both sites in the first season (Figs 4.10a and 4.10b), and only at Cressy in the second season (Fig 5.9). The lack of grain yield at Elliott in 1990 was due to damage to the experiment by livestock immediately prior to harvest.

The relationship between plant density and grain yield was very similar across both seasons (Table 6.6). The site differences were probably due to the crop's groundwater advantage at Cressy. The data (Figs 4.10a and b) indicates that crops at Cressy set higher grain yields with lower plant density. This implies greater podset per plant at Cressy. Such improvements in pod set can be related to good levels of soil moisture at flowering (Biddiscombe, 1975). This supported the possibility of groundwater access. The fact that 75A329 yielded noticeably lower was not necessarily due only to its branch structure. It was an initial determinate type cultivar that was in the process of being bred for its branch structure, rather than high yield. Once good branch structure and pattern of pod production had been developed then no doubt breeders would have concentrated on grain yield improvement. This stage had not been reached at the time of writing.

Given the high R^2 values obtained and the importance and convenience of availability of plant density data, the equation for the Elliott site was used for the empirical model. Although there were minimal differences between the indeterminate cultivars, they were both included in the model.

6.4.1.6 Rainfall/soil moisture/evaporation effects on flowering and maturation of lupins at Elliott and Cressy

The experiments showed that access to additional soil moisture extended the crops growing season and extended development periods such as flowering (Fig 4.5 and 5.4). There were obvious yield benefits here as more flowers set, moisture stress was reduced, and floral abortion was minimised as a result (Biddiscombe, 1975). This resulted in increased grain yield. Previous workers have already established that irrigation of lupins at commencement of flowering has maximum benefit to increasing yield (Stoker, 1975). I also demonstrated the benefit of irrigation during experiments at Elliott in 1988 (Chapter three).

It would be fair to conclude that high soil moisture combined with low evaporation rates at the time of lupin flowering was of benefit to increased grain yields achieved at each site in each season. However, drier soil conditions (high evaporation and low rainfall) were essential late in the season to assist crop maturity and senescence necessary for a successful machine harvest. If moist conditions extended over longer periods, the crop would be slow to reach maturity, and difficult to harvest.

6.4.2 Incorporation of selected relationships into an empirical model

A set of relationships was collected from the integration of both seasons data and linked to form a partial model of lupin crop growth (Fig 6.4). Thermal time based on maximum and minimum temperatures was the major external factor used as data input into the model.

Table 6.6. Regression equations (second order) for plant density/crop grain yield. * = selected for use in empirical model.

Year	Site	Cultivar	Equation	R^2
1989	ERS	Yandee	$Yld = 658.17 + 55.40(den) - 0.28(den)^2$	0.98
		Geebung	$Yld = 322.63 + 68.25(den) - 0.39(den)^2$*	0.97
		75A329	$Yld = 163.93 + 37.08(den) - 0.20(den)^2$	0.96
	CRS	Yandee	$Yld = 2004.40 + 129.90(den) - 1.51(den)^2$	0.99
		Geebung	$Yld = 473.46 + 213.60(den) - 2.51(den)^2$	0.97
		75A329	$Yld = 1111.90 + 45.86(den) - 0.41(den)^2$	0.82
1990	CRS	Yandee	$Yld = 1648.79 + 71.91(den) - 0.535(den)^2$	1.00
		Geebung	$Yld = 2361.89 + 46.82(den) - 0.338(den)^2$	1.00
		75A329	$Yld = 2024.77 + 23.47(den) - 0.196(den)^2$	1.00

6.4.2.1 Testing the empirical model

In order to test the model, the equations were encoded into a spreadsheet and a number of runs made using different thermal time values (Table 6.7).

The model and forecast grain yield

Each yield calculated (Table 6.7) falls within the likely expected range of values for low and medium densities. However, forecast yields are much lower at the higher densities than actually were produced in 1989. This indicates an inherent weakness in the model's calculations when high plant densities are involved. Varying thermal time in test runs 2 to 5 suggested that higher temperatures during the latter part of crop growth are most likely to increase grain yield.

The model and crop development

Crop development, particularly to flowering, appeared likely to be controlled by daylength and, in the case of Geebung, vernalisation as

well rather than just thermal time (Chapter 5). If the latter had been the case it would have been appropriate to use the data collected in these experiments. Instead crop growth rather than development has been concentrated upon.

The model and crop growth

It was evident that the weight of lupin crop dry matter formed by the end of the season was a clear indicator of growth and grain yield. Previous workers (Withers 1975; Goulden, 1976) highlighted the importance of producing lupin plants with maximum lateral pod bearing branches to increase yield. Perry (1975) quantified this with

Table 6.7 Predicted potential grain yields (kg/ha) for each variety, using the model, are shown for each test for low, medium, and high density lupin crop.

Test run	Predicted potential grain yield (kg/ha)								
	Low density			Med density			High density		
	Yand	Geeb	75A	Yand	Geeb	75A	Yand	Geeb	75A
1	1237	1067	780	905	1296	873	1514	1594	1715
2	662	897	767	599	600	676	977	1124	1095
3	1254	1068	780	*	1270	*	*	*	*
4	1178	1069	780	1480	1270	1052	1972	1543	1111
5	597	682	707	508	429	522	678	971	921

Test run 1 = Actual temperature data collected at Elliott in 1989.

Test run 2 = Low temperature. Very slow accumulation of day degrees.

Test run 3 = High temperature. Rapid accumulation of day degrees

Test run 4 = Cold during the first half of crop growth, and hot during the second half

Test run 5 = Hot during the first half of crop growth, and cold during the second half.

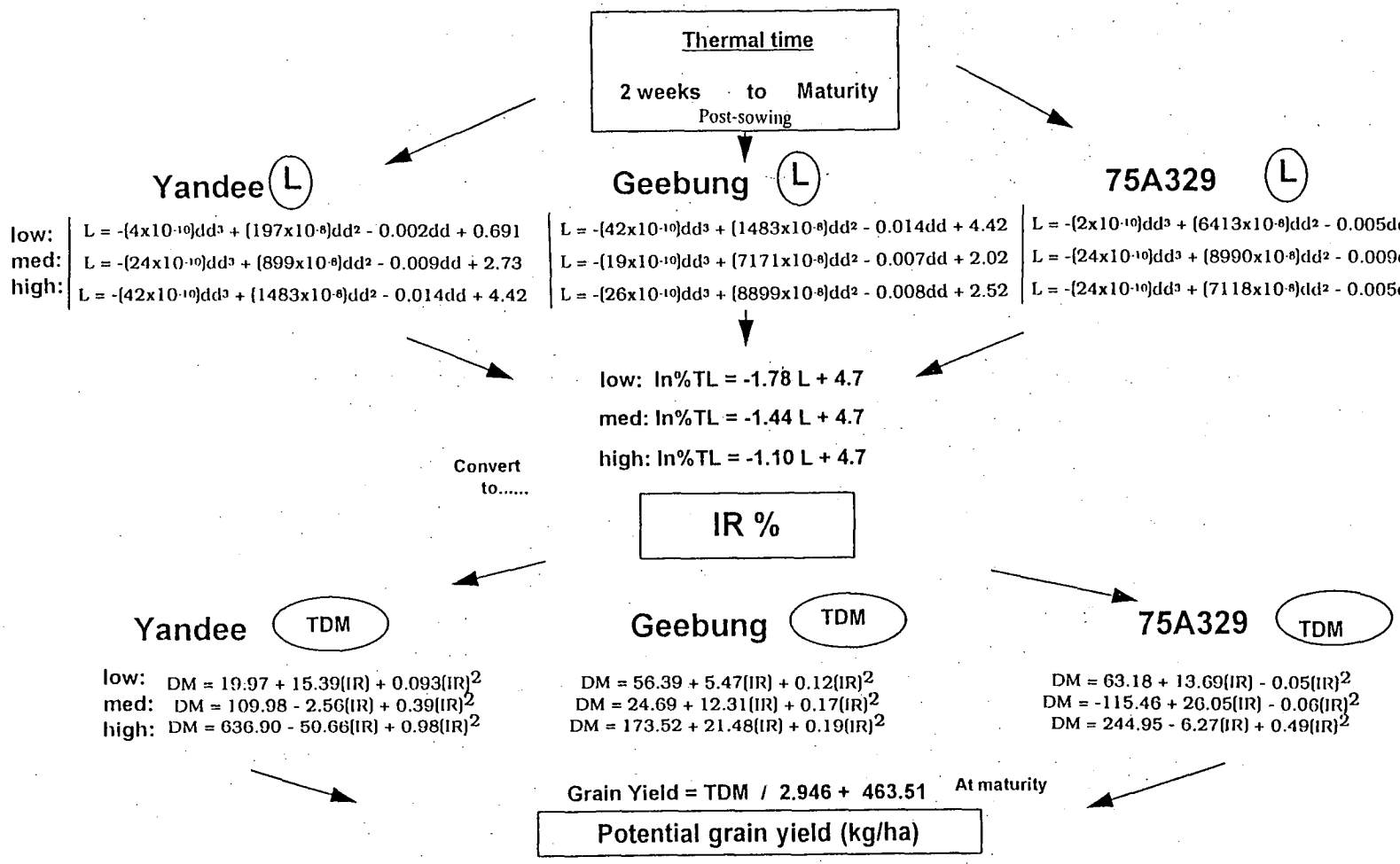

Fig 6.4 Model of data collected in 1989 and 1990 showing regression equations used for each sub-model. Eight equations compose each sub-model to allow for eight data points to be plotted across growth. Each regression equation has been obtained from analysis of data detailed in Chapters 4 and 5.

L = Leaf Area Index TR = Transmitted radiation

IR = Intercepted radiation TDM = Total crop dry matter

Densities: low = 5-25 plants/m^2, med = 25-50 plants m^2

high = >50 plants/m^2

measurements of dry matter on plants growing in a shortened season. Lower grain yields correlated with lower dry matter production.

These findings were supported in the field experiments particularly in the second year (chapter four). The plants grown at Cressy had a higher dry matter weight than Elliott plants. The higher yields at Cressy were attributed to extensive lateral pod bearing branches (dry matter bulk). In the preliminary experiment at Elliott, the site was irrigated at flowering, artificially extending the crop season and providing a higher dry matter bulk and a higher pod set than at Ross.

The role an area's climate has on season length and, consequently, dry matter production is an important component in the modelling strategy. Despite the drier conditions at Cressy, the crop in the first year appeared to develop well into the season with little rainfall and no irrigation. It appeared that the deep rooted lupin plants in the Panshangar sands had tapped into the relatively high water table. They had been able to obtain further moisture in the drier part of the season. This explained the continued branching, despite the apparent lack of favourable rainfall conditions.

Plotting the production of dry matter from sowing to harvest highlights the findings of Greenwood *et al.* (1975) that the lupin plant develops very slowly during its first few months until flowering commences and then starts a rapid accumulation of dry matter over subsequent weeks. The importance of favourable seasonal conditions during this rapid growth period is more apparent as the crop needs maximum time to branch and pod so as to attain its maximum possible yield.

The model bases its predicted potential grain yield on the final estimated total dry matter. This is calculated from the direct relationship of total crop dry matter with intercepted radiation, and its

indirect relationship to L and thermal time. The model could be developed further if continuous in-coming radiation is measured during crop growth. This data would allow the actual efficiency of the crop to be measured by determining the amount of dry matter produced per unit of energy intercepted.

The model and L

Leaf area is important to the crop during growth as its level determines how much photosynthesis occurs and how much dry matter is produced; one factor drives another. Monteith (1979) showed that the rate of crop growth is proportional to the rate of photosynthesis and depends upon the amount of radiant energy intercepted by the foliage. This indicates the importance of leaf area in forecasting crop growth.

L is a second major indicator of lupin crop growth. When L is read in conjunction with the dry matter figure, the growth of plant or crop can be visualised. L measurements at Elliott and Cressy from sowing to harvest indicated that leaf expansion was minimal in the initial few weeks. Leaf area increased at flowering immediately prior to the rapid accumulation of dry matter (resulting from increased photosynthesis). Towards the end of the season, leaf area peaked and then fell. This drop indicates the abscission of leaves at maturity.

The model related L development to thermal time throughout the period of growth. The model suggested that low accumulation of L ultimately resulted in lower yields. This is probably explained by decreased leaf area to intercept light in colder areas, thus photosynthesis is not maximised and the crop's high potential yield is not achieved. It is worth considering that with a longer period of development (early sowing), growth in areas of lower temperature may reach an acceptable L.

The model and rainfall

Seasonal extension by irrigation at flowering during the preliminary experiment at Elliott has already been discussed, as has the crop's continued access to moisture at Cressy during both years resulting in continued plant development, increased dry matter, and increased grain yield.

During both main experiments (chapters four and five), soil water deficits were calculated to provide an insight into the important role soil water has in plant development.

Although rainfall had originally been intended to be used as part of the model, preliminary exploratory data analysis could find no significant quantitative relationships between growth, development, and rainfall. This emphasises the fact that rainfall (and irrigation) when considered on its own has little relevance for crop growth. It is the water holding capacity of the soil in conjunction with rainfall and irrigation that needs to be considered. Soil water responses of lupins were shown in this study (chapters 4 and 5). Further development of this model could include links with a soil water model.

Jamieson and Wilson (1988) developed a model of wheat growth that is based on crop access to water. Such a detailed approach to crop water use enables the effects of water stress on crop growth to be simulated and studied. Further experiments that look at a wider range of data sets could be conducted, the results of which would strengthen the model.

The model and plant density

The ideal model of lupin growth could relate variable plant densities to growth and development as an integrated part of an empirical model. The approach taken in this study produced separate sub-models for density groupings (low, medium, and high) for each of the three

cultivars tested. A separate yield and dry matter forecast is produced for each group. The basis for each group is the range of plant densities counted in each group and these ranges are given on the spreadsheet (Appendix F).

6.5 Conclusions

1. Lupin growth and the crop's potential in Tasmania.

Yandee, Geebung, and 75A329 can all be successfully cultivated in Tasmania. The indeterminate cultivars, Yandee and Geebung, produced higher grain yields than the determinate 75A329, a cultivar that as yet has not been bred specifically for high grain yield. The indeterminate cultivars are a more commercial proposition based on the economic comparisons made in Appendix E. When compared to other crops the gross margin of lupins in Tasmania is low hence the need to maximise the yield potential of the lupin crop using the best yielding cultivar under the optimum environmental conditions. In autumn sowing, Geebung is the preferred cultivar producing a higher yield in both the northwest and the midland regions of Tasmania.

2. Lupin growth.

In general, emergence and initial development of lupin plants is very slow. Rapid accumulation of dry matter follows this period. During this stage, temperature and soilwater availability affect the amount of drymatter and leaf area produced. The higher the dry matter at crop maturity the higher the grain yield. Thus a site that maximises this final dry matter figure will maximise grain yield.

There are other effects of the climate at a site further to dry matter accumulation. A sowing time must be selected at a site to

minimise moisture stress at flowering and thus maximise potential yield. In dryland situations, early (May) sowing also gives a longer period of development likely to result in higher yields than later (winter or spring) sowing.

Where irrigation is available, and the cultivar does not have a vernalisation requirement, lupin crops can be planted much later into the year. Flowering will occur in summer due to long days; irrigation on well drained soils can extend the flowering period and prevent premature pod abortion. Obviously in dry land situations this would not be possible.

3. The model

The model I have presented in this thesis is a summary of the data collected on lupin growth over a two year period at two sites, Elliott and Cressy, in Tasmania. Its predictive ability outside of the data on which it is based is doubtful. The sub-models (eg. L versus thermal time) were developed to examine such factors as the pattern of leaf area development on a thermal scale.

It is recognised that a complete model has its sub-routines, one generating the development data, days for leaf expansion, and grain production based on temperature, photoperiod, water stress, and other factors. Other sub-routines develop leaf area then predict weekly dry matter. And so each sub-routine interacts to literally model the growth of the crop.

The model developed in this study provides useful information to assist in site assessment. More importantly it demonstrates the importance of air temperatures during crop maturity and some of the mathematical relationships between crop growth and yield. Although never intending to approach the complexity of models such as ARCWHEAT1 (Weir *et al.*, 1984), SIRAGCROP (Stapper and Murray,

1986), or ALFALFA (Denison and Loomis, 1989), the relationships established in this study are suitable for further development into such complex crop model systems.

This study demonstrated the principle of collecting agronomic data and, guided by basic plant physiological principles and mathematical procedures, assembling simple sub-models that when linked can approximate a particular aspect of crop growth. The data collected and the subsequent descriptive model has satisfied the purpose of this thesis in moving a step closer to a crop growth, development, and yield model for *Lupinus angustifolius* in Tasmania.

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APPENDIX A: Experiment site descriptions.

Appendix A3.1. Description of experiment sites used in 1988.

Descriptor	Elliott	Ross
Rain (annual mean mm)	1200	408
Rain (1988 season mm)	498	316
Soil type	krasnozem	sandy loam
Soil pH	5.5	n.a
Site history:1987	barley	pasture
Site history:1986	potato	pasture

Appendix A4.1. Description of experiment sites used in 1989.

Descriptor	Elliott	Cressy
Rain (annual mm)	1200	634
Rain (season mm)	259	394
Soil type	krasnozem	panshangar sands
Soil pH	4.7	4.2
P level	47	92
K level	80	245
Site history: 1988	pasture	subclover
Site history: 1987	(20 years)	barley
Site history: 1986		pasture

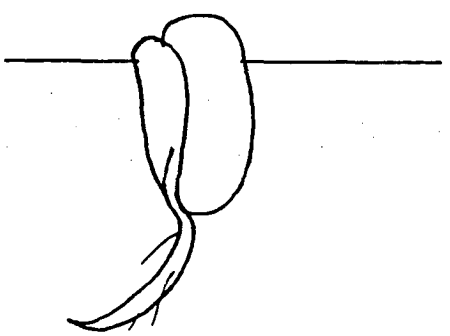
Appendix A4.2. Description of experiment sites used in 1990.

Descriptor	Elliott	Cressy
Rain (mean ann. mm)	1200	634
Rain (grow season mm)		
Soil type	krasnozem	panshangar sands
Soil pH	4.9	4.2
P level	74	n.a
K level	520	n.a
Site history: 1989	barley	barley
Site history	peas	pasture

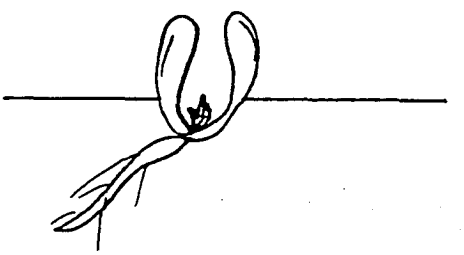
n.a = not available

APPENDIX B: Growth stages of the narrow leafed lupin.

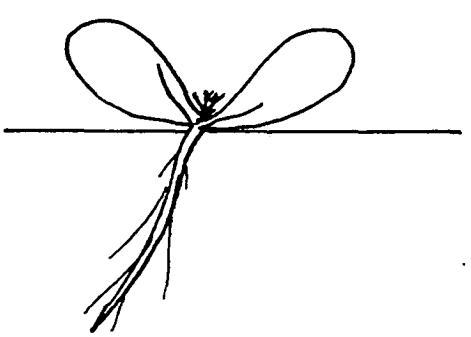
Stage A1: Seed has germinated and just broken through the soil surface.



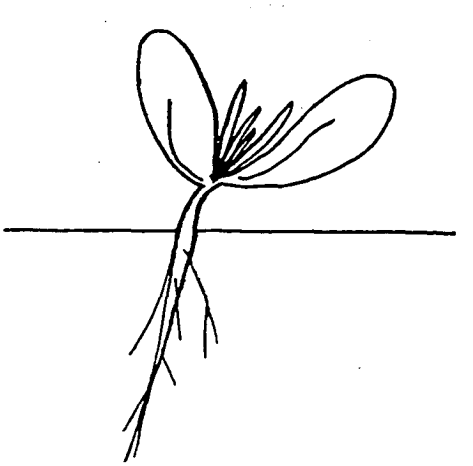
Stage A2: Seed cotyledons are above soil surface and have commenced to expand.



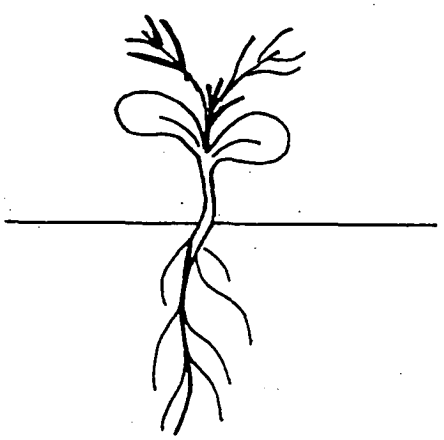
Stage A3: Seed cotyledons are fully expanded and first pair of leaflets are visible.



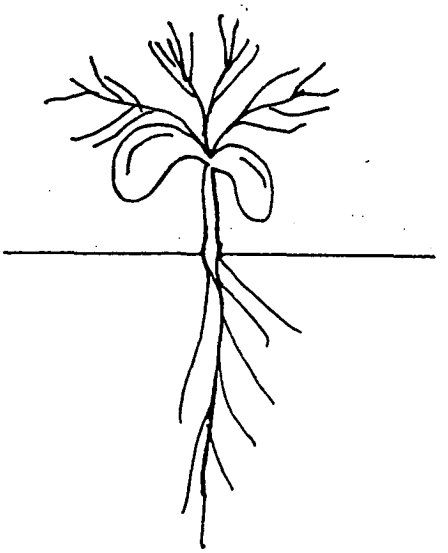
Stage A4: Plant stem clearly visible. First pair of leaflets enlarged and starting to expand.



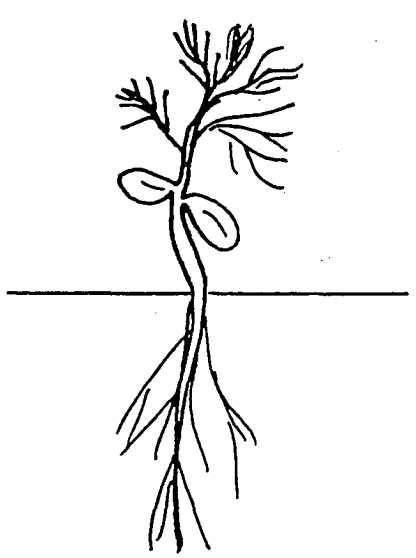
Stage A5: Two-leaf. First leaflet pair are fully expanded.



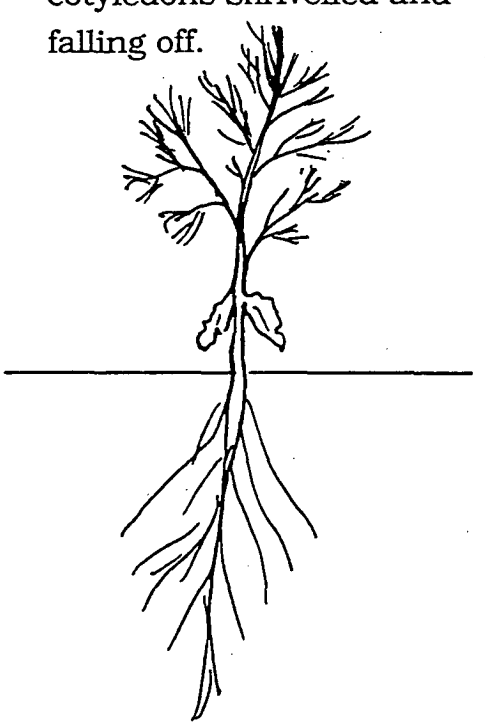
Stage A6: Second pair of leaflets are starting to expand.



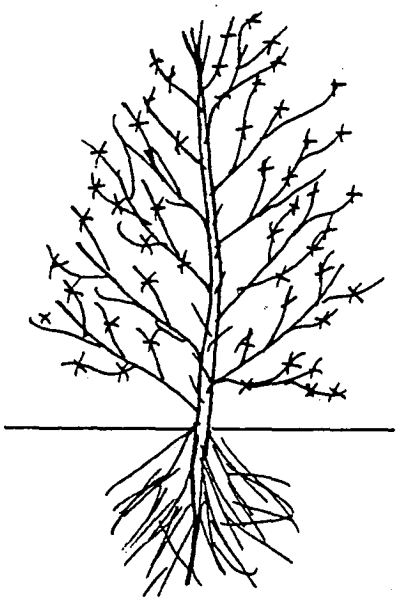
Stage A7: Four-leaf. Two sets of leaflets are fully expanded. Further unexpanded leaflets are visible.



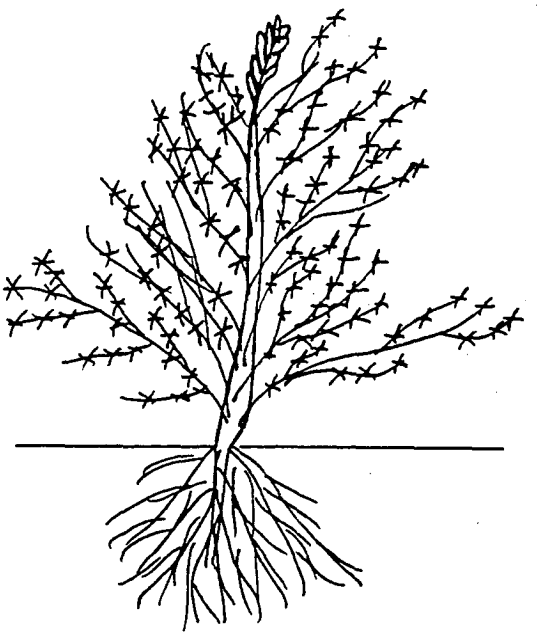
Stage A8: Eight-leaf minimum. Secondary branches visible. Seed cotyledons shrivelled and falling off.



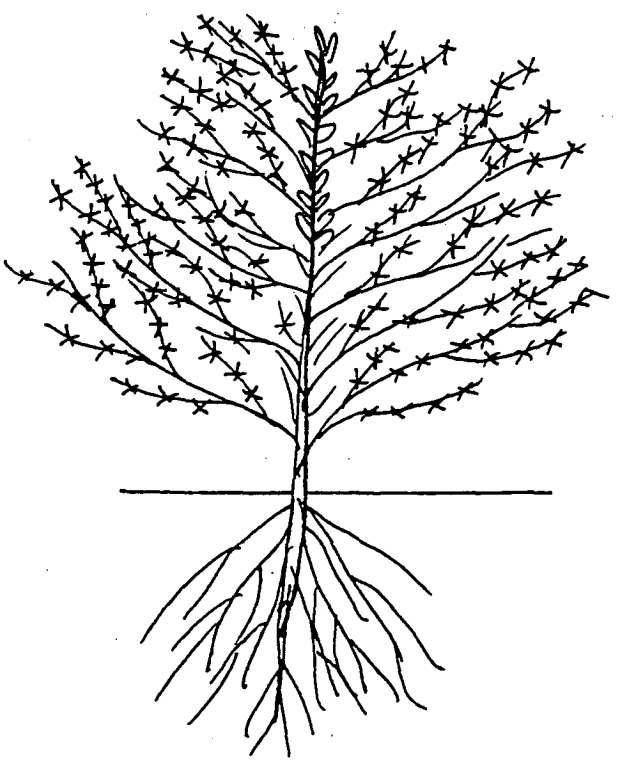
Stage B1: Advanced growth of secondary branching. Primary stem has ten or more sets of leaflets.



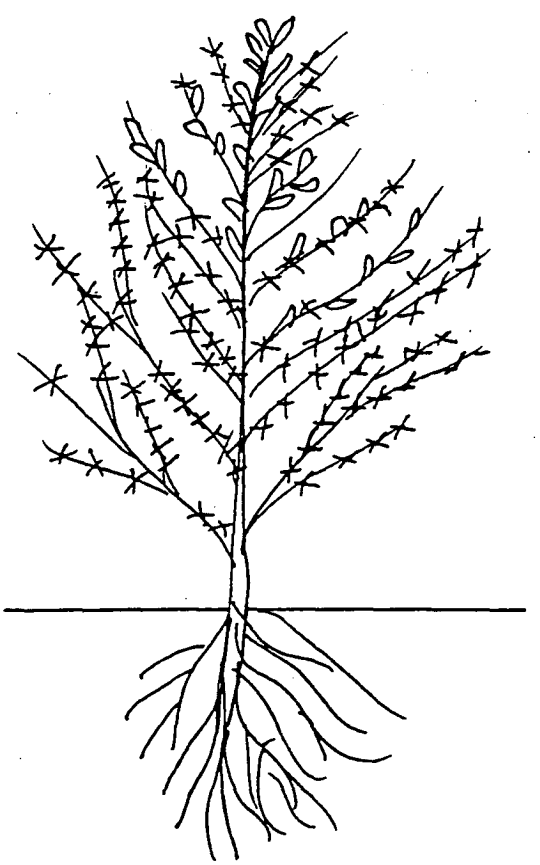
Stage B2: Well developed secondary branches. Flower buds in unopened cluster at plant apex.



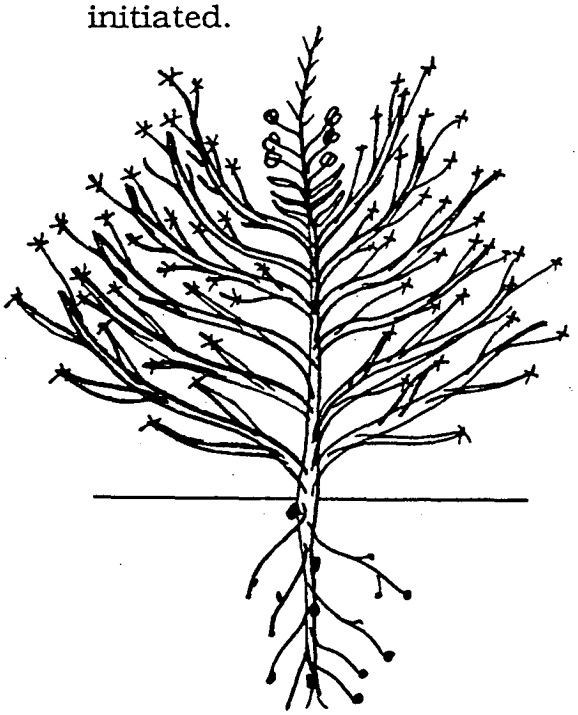
Stage C1: Flower buds starting to open. Buds spaced apart with extension of internode. Approximately 20% of crop in flower.



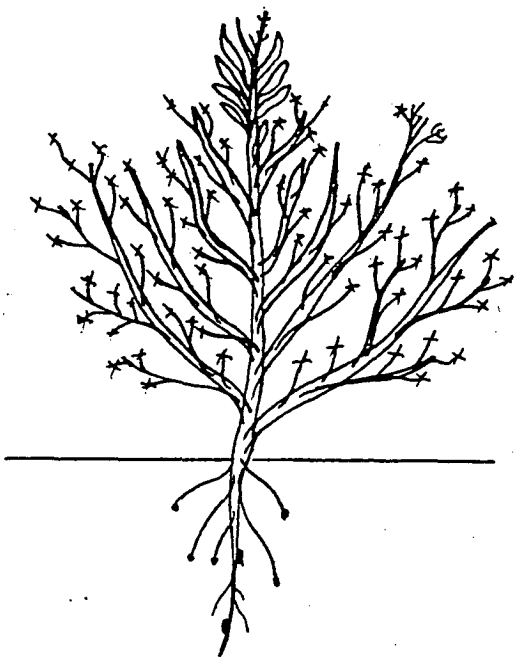
Stage C2: Approximately 50% of crop in flower.



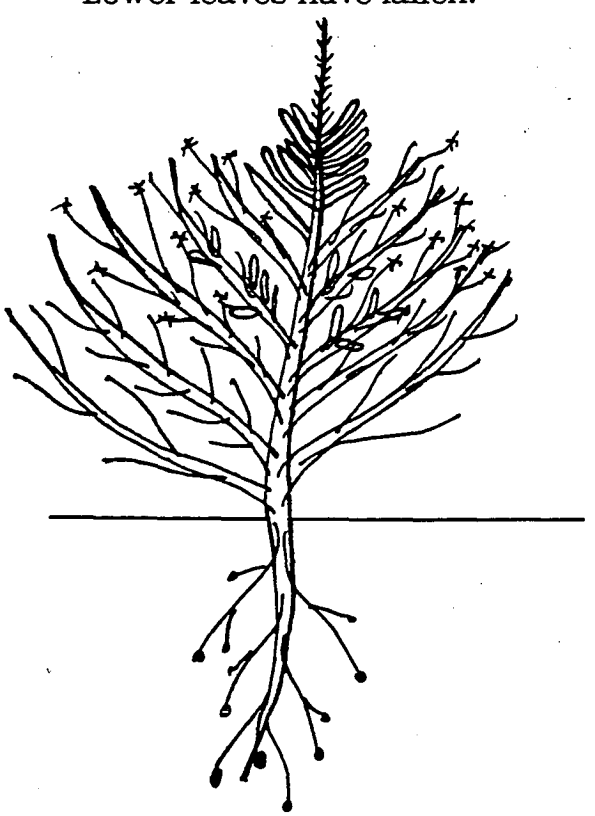
Stage C3: Approximately 90% of crop in flower. Some flowers aborted at top of primary stem. Pods initiated.



Stage D1: Flowering complete. Plant fully podded. Pods full size and green. Lower pods starting to yellow.



Stage D2: Plants senescing. Lower leaves have fallen.



Stage D3: Few, if any leaves on plant. Pods brown but grain still doughy.

Stage D4: Entire plant dry. Seeds rattle in pods. Pods crack open easily. Crop is ready to harvest.

APPENDIX C: Climate data for Elliott and Cressy

Appendix C3.1. Meteorological data for Elliott comparing long term climatic means with 1989 data.

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Rainfall✣								
1990	144	163	97	173	150	28	54	17
longterm✷	128	165	154	116	108	79	81	45
Evaporation.✖								
1990	1.2	1.2	1.6	2.5	3.0	4.0	5.2	6.0
longterm☆	0.9	1.2	1.6	2.5	3.5	4.3	4.9	5.4
Max.temp(°C)								
1990	11.9	12	12	13.8	14.9	17.9	19.6	20.6
longterm✷	11.7	10.9	11.6	13.3	15.1	17.2	19.0	20.2
Min.temp(°C)								
1989/90	4.5	4.9	4.2	5.6	6.0	9.1	9.6	11.1
longterm✷	5.2	4.8	4.8	5.8	7.3	8.4	9.9	10.8

✣ = Rainfall measured as total monthly in mm. ✷ = 1954 to 1990

✖ = Class A pan mean daily in mm. ☆ = 1980 to 1990

Appendix C3.2. Meteorological data for Cressy comparing long term climatic means with 1989 data.

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Rainfall✣								
1990	80	69	41	72	54	12	59	10
longterm✹	52	73	68	58	55	49	51	36
Evaporation.✖								
1990	0.9	1.3	1.2	2.1	2.1	4.6	5.6	5.7
longterm☆	0.7	0.7	1.0	1.9	2.6	4.4	5.4	5.0
Max.temp(°C)								
1990	10.8	11.2	12.4	14.8	11.6	20.3	22.2	24.1
longterm✹	11.3	10.6	12.1	14.2	17.3	18.8	21.2	23.5
Min.temp(°C)								
1989/90	-1.2	0.3	-1.1	1.5	1.5	5.3	5.2	6.1
longterm✹	1.8	0.9	1.9	3.3	4.9	6.4	7.9	9.3

✣ = Rainfall measured as total monthly in mm. ✹ = 1954 to 1990

✖ = Class A pan mean daily in mm. ☆ = 1980 to 1990

Appendix C4.1. Meteorological data for Elliott comparing long term climatic means with 1990 data.

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Rainfall✣								
1990	135	147	158	106	102	85	72	65
longterm✷	128	165	154	116	108	79	81	45
Evaporation.✖								
1990	1.6	1.4	1.7	2.2	4.0	5.4	4.3	5.0
longterm☆	0.9	1.2	1.6	2.5	3.5	4.3	4.9	5.4
Max.temp(°C)								
1990	12.0	11.4	11.6	13.4	15.8	18.1	19.7	21.4
longterm✷	11.7	10.9	11.6	13.3	15.1	17.2	19.0	20.2
Min.temp(°C)								
1989/90	5.5	4.6	3.4	6.1	7.2	8.6	10.4	11.1
longterm✷	5.2	4.8	4.8	5.8	7.3	8.4	9.9	10.8

✣ = Rainfall measured as total monthly in mm. ✷ = 1954 to 1990

✖ = Class A pan mean daily in mm. ☆ = 1970 to 1990

Appendix C4.2. Meteorological data for Cressy (measured at Launceston airport) comparing long term climatic means with 1990 data.

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Rainfall✣								
1990	79	60	114	39	64	56	41	-
longterm✹	62	81	80	65	63	51	53	-
Evaporation✖								
1990	0.8	1.1	1.2	2.3	3.5	5.1	6.3	-
longterm☆	1.0	1.0	1.5	2.4	6.6	-	6.4	-
Max.temp[°C]								
1990	12.0	11.4	10.9	13.9	16.6	19.2	21.6	-
longterm✹	11.3	10.7	12.0	14.0	16.3	18.6	21.0	-
Min.temp[°C]								
1990	2.6	3.1	2.0	4.2	6.2	7.8	9.6	-
longtermY	4.2	4.7	5.2	6.3	7.6	8.1	8.6	-
Sunshine✪								
1990	4.6	4.6	5.9	6.6	7.7	9.8	8.7	-
longterm☆	4.2	4.7	5.2	6.3	7.6	8.1	8.6	-

✣ = Rainfall measured as total monthly in mm. ✹ = 1954 to 1990

✖ = Class A pan mean daily in mm. ☆ = 1970 to 1990

✪ = Sunshine measured as mean daily in hours

APPENDIX D: ANOVA tables for experimental data

Appendix D3.1. Mean data for actual plant densities counted at three sites in 1988/89. Includes S.O.V. and D.F.

Cultivar	Elliott (psm)	Ross (psm)	Cressy (psm)
Yandee Geebung 75A329	13.33 55.33 85.33 & 10 other cultivars	12.00 20.00 16.00 & 3 other cultivars	33.33 32.00 n.a. & 6 other cultivars
Reps F Pr SED $LSD_{0.05}$	3 * 19 53	3 n.s. - -	3 n.s. - -
S.O.V Block Cultivar Error Total	D.F. 2 12 24 38	D.F. 2 5 10 17	D.F. 2 8 16 26

n.s. = not significant n.a. = not available psm = plants/m^2

* = significant at 5% level

Appendix D3.2.. Mean data for lupin cultivar phenology at Elliott in 1988/89. Includes S.O.V. and D.F.

Cultivar	S-F(d)	F(d)	S-M(d)
Yandee Geebung 75A329 & 10 others	78.00 79.00 73.00	18.00 21.00 29.00	131.00 152.00 139.00
Reps F Pr SED $LSD_{0.05}$	3 * 0.82 1.99	3 * 0.82 1.99	3 * 0.82 1.99
S.O.V Block Cultivar Error Total	D.F. 2 12 24 38	D.F. 2 12 24 38	D.F. 2 12 24 38

S-F(d) = Days from sowing to flowering
F(d) = Days in flower
S-M(d) = Days from sowing to maturity

Appendix D3.3. Mean data for lupin cultivar phenology at Ross in 1988/89. Includes S.O.V. and D.F.

Cultivar	S-F(d)	F(d)	S-M(d)
Yandee Geebung 75A329 & 3 others	138.00 139.00 180.00	21.00 21.00 29.00	220.00 219.00 147.00
Reps F Pr SED $LSD_{0.05}$	3 * 0.82 1.99	3 * 0.82 1.99	3 * 0.82 1.99
S.O.V Block Cultivar Error Total	D.F. 2 5 10 17	D.F. 2 5 10 17	D.F. 2 5 10 17

S-F(d) = Days from sowing to flowering
F(d) = Days in flower
S-M(d) = Days from sowing to maturity

Appendix D3.4. Mean data for lupin cultivar phenology at Cressy in 1988/89. Includes S.O.V. and D.F.

Cultivar	S-F(d)	F(d)	S-M(d)
Yandee Geebung 75A329 & 6 others	131.00 126.00 -	21.00 21.00 -	231.00 231.00 -
Reps F Pr SED $LSD_{0.05}$	3 * 1.00 2.45	3 n.s. - -	3 n.s. - -
S.O.V Block Cultivar Error Total	D.F. 2 8 16 26	D.F. 2 8 16 26	D.F. 2 8 16 26

S-F(d) = Days from sowing to flowering
F(d) = Days in flower
S-M(d) = Days from sowing to maturity

Appendix D3.5. Mean data for lupin cultivar yield components at Elliott in 1988/89. Counts made on 10 individual plants from each block. Includes S.O.V. and D.F.

Cultivar	Pods/plant	Seeds/pod	100 seed (g)	Seed/ha (kg)◆
Yandee	33.73	3.90	23.00	11857.00
Geebung	17.97	4.57	20.33	8351.00
75A329	19.83	3.83	17.35	3942.00
Reps	3	3	3	3
F Pr	*	*	*	*
SED	7.88	0.930	0.035	3543.43
$LSD_{0.05}$	15.68	1.850	0.070	7051.42
S.O.V	D.F.	D.F.	D.F.	D.F.
Block	2	2	2	2
Cultivar	2	2	2	2
Interact	4	4	4	4
Error	81	81	81	81
Total	89	89	89	89

* = significant at the 5% level

◆ = calculated from other yield components.

Appendix D3.6. Mean data for lupin cultivar yield components at Ross in 1988/89. Counts made on 10 individual plants from each block. Includes S.O.V. and D.F.

Cultivar	Pods/plant	Seeds/pod	100 seed (g)	Seed/ha (kg)◆
Yandee	22.90	3.65	22.33	4631.10
Geebung	14.07	3.37	23.00	4484.40
75A329	19.93	3.37	14.99	2603.90
Reps	3	3	3	3
F Pr	*	n.s.	n.s.	*
SED	8.49	-	-	1868.16
$LSD_{0.05}$	16.89	-	-	3717.63
S.O.V	D.F.	D.F.	D.F.	D.F.
Block	2	2	2	2
Cultivar	2	2	2	2
Interact	4	4	4	4
Error	81	81	81	81
Total	89	89	89	89

n.s. = not significant * = significant at the 5% level

◆ = calculated from other yield components

Appendix D4.1. Mean data for lupin cultivar plant densities and yield components at Cressy in 1989/1990. ANOVA data between densities and between cultivars. Includes S.O.V. and D.F.

Cultivar	PSM target	PSM actual	Pods m^2	Pods plant	Seeds pod	Seeds 100(g)	Seed kg/ha	TDM kg/ha
Yandee	10	8	428.30	57.10	4.15	16.00	2830	7950
Yandee	40	29	652.00	25.20	3.78	17.80	4482	12000
Yandee	160	71	524.00	7.30	3.68	18.70	3615	11670
Reps	-	4	4	4	4	4	4	4
F Pr	-	*	n.s.	*	n.s.	*	n.s.	n.s.
SED	-	9.06	-	9.80	-	0.82	-	-
$LSD_{0.05}$	-	19.92	-	21.56	-	1.89	-	-
Geebung	10	8	508.80	60.30	4.41	16.60	1638	8180
Geebung	40	16	513.00	31.40	3.94	18.50	3590	9700
Geebung	160	64	565.00	10.00	4.10	17.20	3893	10570
Reps	-	4	4	4	4	4	4	4
F Pr	-	*	n.s.	*	n.s.	n.s.	n.s.	n.s.
SED	-	7.76	-	11.37	-	-	-	-
$LSD_{0.05}$	-	17.07	-	25.02	-	-	-	-
75A329	10	4	148.70	37.30	3.89	15.70	989	2410
75A329	40	8	322.50	30.50	4.07	13.90	1377	4240
75A329	160	49	452.00	10.30	3.78	14.10	2413	5070
Reps	-	4	4	4	4	4	4	4
F Pr	-	*	*	*	n.s.	n.s.	*	n.s.
SED	-	8.76	90.54	9.24	-	-	645	-
$LSD_{0.05}$	-	19.26	199.19	20.32	-	-	1419	-
S.O.V	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.
Block	-	3	3	3	3	3	3	3
Cultivar	-	2	2	2	2	2	2	2
Error	-	6	6	6	6	6	6	6
Total	-	11	11	11	11	11	11	11
Yandee	-	35.92	534.80	29.85	3.87	17.47	3642	10540
Geebung	-	30.33	528.90	33.91	4.15	17.45	3751	9483
75A329	-	21.08	307.80	26.04	3.93	14.56	1741	3907
Reps	-	3	3	3	3	3	3	3
F Pr		n.s.	*	n.s.	n.s.	*	*	*
SED		-	133.55	-	-	1.63	881.74	2130.20
$LSD_{0.05}$		-	272.45	-	-	3.32	1798.74	4345.60
S.O.V	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.
Block		3	3	3	3	3	3	3
Cultivar		2	2	2	2	2	2	2
Interact		6	6	6	6	6	6	6
Error		24	24	24	24	24	24	24
Total		35	35	35	35	35	35	35

n.s. = not significant * = significant at the 5% level PSM = Plants/m^2
TDM = Total dry matter produced

Appendix D4.2. Mean data for lupin cultivar plant densities and yield components at Elliott in 1989/1990. ANOVA data between densities and between cultivars. Includes S.O.V. and D.F.

Cultivar	PSM target	PSM actual	Pods m^2	Pods plant	Seeds pod	Seeds 100(g)	Seed kg/ha	TDM kg/ha
Yandee	10	12	233.30	19.10	3.71	17.80	1544	3215
Yandee	40	25	281.30	11.50	3.36	18.30	1739	3708
Yandee	160	117	509.00	4.40	3.27	19.80	3324	8011
Reps	-	4	4	4	4	4	4	4
F Pr	-	*	*	*	*	*	*	*
SED	-	10.33	46.85	2.23	0.11	0.41	311.48	852.80
$LSD_{0.05}$	-	22.72	103.06	4.90	0.24	0.91	685.25	1876.20
Geebung	10	13	230.50	16.90	3.77	16.10	1475	2902
Geebung	40	19	239.70	13.00	3.67	15.90	1421	2829
Geebung	160	107	506.00	5.00	3.54	17.40	3143	7079
Reps	-	4	4	4	4	4	4	4
F Pr	-	*	*	*	n.s.	n.s.	*	*
SED	-	13.71	26.55	2.29	-	-	171.08	33.71
$LSD_{0.05}$	-	30.16	58.40	5.04	-	-	376.37	74.17
75A329	10	10	106.80	10.40	3.19	14.30	485	1018
75A329	40	20	224.00	11.15	3.40	14.00	1088	2211
75A329	160	79	430.50	5.50	3.36	14.50	1855	4281
Reps	-	4	4	4	4	4	4	4
F Pr	-	*	*	*	n.s.	n.s.	*	*
SED	-	12.78	72.46	1.39	-	-	290.21	71.28
$LSD_{0.05}$	-	28.12	159.41	3.05	-	-	638.47	156.82
S.O.V	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.
Block	-	3	3	3	3	3	3	3
Cultivar	-	2	2	2	2	2	2	2
Error	-	6	6	6	6	6	6	6
Total	-	11	11	11	11	11	11	11
Yandee	-	51.17	341.20	11.65	3.45	18.62	2202.40	4978
Geebung	-	46.08	325.30	11.61	3.66	16.43	2013.10	4270
75A329	-	36.42	253.80	9.00	3.21	14.23	1142.70	2503
Reps	-	4	4	4	4	4	4	4
F Pr		n.s.	n.s.	n.s.	*	*	*	*
SED		-	-	-	0.19	0.83	76.30	195.07
$LSD_{0.05}$		-	-	-	0.39	1.69	155.60	397.93
S.O.V	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.	D.F.
Block		3	3	3	3	3	3	3
Cultivar		2	2	2	2	2	2	2
Interact		6	6	6	6	6	6	6
Error		24	24	24	24	24	24	24
Total		35	35	35	35	35	35	35

* = significant at the 5% level n.s. = not significant PSM = Plants/m^2
TDM = Total dry matter produced

Appendix D5.1. Mean data for lupin cultivar plant densities and yield components at Cressy in 1990/91. ANOVA data between densities and between cultivars. Includes S.O.V. and D.F.

Cultivar	PSM target	PSM actual	Seed kg/ha
Yandee	10	11	2375
Yandee	40	27	3190
Yandee	160	103	3401
Reps	-	-	3
F Pr	-	-	n.s.
SED	-	-	-
$LSD_{0.05}$	-	-	-
Geebung	10	2	2881
Geebung	40	46	3790
Geebung	160	105	3541
Reps	-	-	3
F Pr	-	-	n.s.
SED	-	-	-
$LSD_{0.05}$	-	-	-
75A329	10	8	2163
75A329	40	37	2610
75A329	160	94	2466
Reps	-	-	3
F Pr	-	-	n.s.
SED	-	-	-
$LSD_{0.05}$	-	-	-
S.O.V	D.F.	D.F.	D.F.
Block	-	2	2
Cultivar	-	2	2
Error	-	4	4
Total	-	8	8
Yandee	-	47	2988.67
Geebung	-	51	3404.00
75A329	-	46	2413.00
Reps	-	-	3
F Pr	-	-	*
SED	-	-	406.33
$LSD_{0.05}$	-	-	848.00
S.O.V	D.F.	D.F.	D.F.
Block	-	2	2
Cultivar	-	2	2
Density	-	2	2
Error	-	20	20
Total	-	26	26

* = significant at the 5% level n.s. = not significant
PSM = Plants/m^2

APPENDIX E: Economics of narrow leafed lupin production in Tasmania

Table E1. Gross Margin Analysis for cropping lupins in Tasmania (DPIF, 1993)

							$/ha
GROSS INCOME							
Yield:	2.0 t/ha						
Price:	$280.00 /tonne						560
Total Gross Income							560
VARIABLE COSTS							
Materials:							
Seed:			100 kg/ha @		$600.00 /tonne		60
	Inoculation of seed				$8.00 /tonne		1
Fertiliser:	Super		250 kg/ha @		$238.55 /tonne		60
			(applied with seed)				
Weed Control:	metribuzin	1 spray @	0.6 L/ha @		$69.92 /L		42
Pest Control:	chlorpyrifos	1 spray @	0.9 L/ha @		$20.10 /L		18
Tractor and Plant:							
Land Preparation:			3.2 hr/ha @		$13.76 /hr		44
Drilling:			0.7 hr/ha @		$13.76 /hr		10
Weed Control:			0.5 hr/ha @		$8.57 /hr		4
Contract:							
Pest Control:	Aerial Spray		1 spray @		$25.00 /ha		25
Harvesting:			$53 /ha				53
Excess:			$26 /t over		2.5 tonnes		0
Bin:			$1 /tonne				2
Cartage:			$13 /tonne				26
Total Variable Costs							345
GROSS MARGIN							215

Table E2. Gross Margin analysis of lupin production in Tasmania based on forecast grain yields produced using the growth model.

* Test run 4, Medium density Yandee (Table 6.7).

						$/ha	Your Estimate
GROSS INCOME							
Yield:	2.0 t/ha						1.4
Price:	$280.00 /tonne					560	280
Total Gross Income						560	392
VARIABLE COSTS							
Materials:							
Seed:			100 kg/ha @		$600.00 /tonne	60	
	Inoculation of seed				$8.00 /tonne	1	
Fertiliser:	Super		250 kg/ha @		$238.55 /tonne	60	
			(applied with seed)				
Weed Control:	metribuzin	1 spray @	0.6 L/ha @		$69.92 /L	42	
Pest Control:	chlorpyrifos	1 spray @	0.9 L/ha @		$20.10 /L	18	
Tractor and Plant:							
Land Preparation: *			3.2 hr/ha @		$13.76 /hr	44	
Drilling:			0.7 hr/ha @		$13.76 /hr	10	
Weed Control:			0.5 hr/ha @		$8.57 /hr	4	
Contract:							
Pest Control:	Aerial Spray		1 spray @		$25.00 /ha	25	
Harvesting:			$53 /ha			53	
Excess:			$26 /t over		2.5 tonnes	0	
Bin:			$1 /tonne			2	
Cartage:			$13 /tonne			26	
Total Variable Costs						345	345
GROSS MARGIN						215	47

* Land Preparation is assumed to consist of a disc ploughing, one disc cultivation and a harrowing.

Table E3. Gross margin comparison of narrow leafed lupins compared with some other crops produced in Tasmania (DPIF, 1993).

CROP	Gross Margin ($/ha)
Barley-Feed(Franklin)-dryland	256
-Feed(Franklin)-high input	373
-Feed(Franklin)-min. cult.	178
Barley-Malting(Franklin)-dryland	235
-Malting(Franklin)-irrig.	335
-Malting(Proctor)-dryland	87
Beans - Broad	294
Buckwheat	720
Fennel	639
Lucerne	366
Lupins-dryland	215
Oats (Esk)-Autumn sown	-19
Oats (Quamby)-Spring sown	137
Peas - Field -dryland	120
- Green -irrigated	566
Peppermint	1150
Poppies - dryland	963
- irrigated	1566
Potatoes (Russets) -processing	3545
Ryegrass (Annual) -cert. seed	1110
(Perennial) -cert. seed	711
Triticale-dryland (early Winter)	215
Wheat- dryland	231
Wheat (Longbow)- dryland	294

APPENDIX F: Spreadsheet of empirical lupin growth model.

An Empirical model for Lupin growth

	Plant dens
	35.00

Input thermal time for eight periods over crop growth

	Daydegrees
1.00	11.00
2.00	258.00
3.00	517.00
4.00	781.00
5.00	1065.00
6.00	1390.00
7.00	1821.00
8.00	2100.00

Conditions
Period 1 = 2weeks
Period 8 = Maturity

Low = Plant density 5 to 25
Med = Plant density 25 to 50
High = Plant density > 50

		Daydegrees	Yandee				Gaebung				75A329			
			LAI	Low	Med	High	LAI	Low	Med	High	LAI	Low	Med	High
1.00		11.00	1.00	0.67	2.63	4.27	1.00	4.27	1.94	2.43	1.00	0.00	2.63	1.28
2.00		258.00	2.00	0.30	0.97	1.72	2.00	1.72	0.66	1.00	2.00	-0.78	0.97	0.44
3.00		517.00	3.00	0.13	0.15	0.67	3.00	0.67	0.05	0.40	3.00	-0.79	0.16	0.29
4.00		781.00	4.00	0.14	0.04	0.53	4.00	0.53	0.02	0.40	4.00	0.02	0.04	0.59
5.00		1065.00	5.00	0.31	0.44	1.26	5.00	1.26	0.40	0.95	5.00	1.81	0.44	1.15
6.00		1390.00	6.00	0.84	1.14	2.33	6.00	2.33	1.04	1.61	6.00	5.01	1.14	1.66
7.00		1821.00	7.00	1.17	1.66	2.74	7.00	2.74	1.56	1.96	7.00	11.05	1.66	1.91
8.00		2100.00	8.00	1.47	1.25	1.52	8.00	1.52	1.34	0.89	8.00	18.03	1.25	-0.93

			Yandee				Gaebung				75A329			
			IR%	Low	Med	High	IR%	Low	Med	High	IR%	Low	Med	High
1.00		11.00	1.00	3.51	0.91	0.01	1.00	-2.90	1.90	2.02	1.00	4.80	0.91	3.33
2.00		258.00	2.00	4.17	3.31	2.80	2.00	1.63	3.75	3.60	2.00	6.05	3.31	4.31
3.00		517.00	3.00	4.47	4.49	4.08	3.00	3.69	4.62	4.26	3.00	6.10	4.49	4.38
4.00		781.00	4.00	4.45	4.64	4.12	4.00	3.75	4.67	4.19	4.00	4.68	4.64	4.05
5.00		1065.00	5.00	4.14	4.06	3.33	5.00	2.40	4.12	3.65	5.00	1.47	4.06	3.43
6.00		1390.00	6.00	3.56	3.05	2.13	6.00	0.65	3.20	2.93	6.00	-4.22	3.05	2.67
7.00		1821.00	7.00	2.62	2.31	-1.66	7.00	-0.18	2.43	2.76	7.00	-14.98	2.31	3.26
8.00		2100.00	8.00	2.08	2.90	3.02	8.00	1.99	2.76	3.72	8.00	-23.03	2.90	4.73

			Yandee				Gaebung				75A329			
			IR%	Low	Med	High	IR%	Low	Med	High	IR%	Low	Med	High
1.00		11.00	1.00	66.59	97.52	98.99	1.00	99.94	93.31	92.43	1.00	0.62	97.52	77.07
2.00		258.00	2.00	35.46	72.61	83.48	2.00	94.68	67.41	63.55	2.00	-332.10	72.61	33.44
3.00		517.00	3.00	12.50	11.19	40.36	3.00	59.82	-1.59	28.47	3.00	-347.39	11.19	18.77
4.00		781.00	4.00	14.32	-3.61	38.69	4.00	67.27	-6.83	33.86	4.00	-6.99	-3.61	42.84
5.00		1065.00	5.00	38.93	41.87	72.42	6.00	88.27	38.40	61.60	6.00	86.66	41.87	69.02
6.00		1390.00	6.00	65.00	76.83	91.66	6.00	98.27	75.43	81.35	6.00	89.89	76.83	81.31
7.00		1821.00	7.00	86.21	89.93	84.61	7.00	99.16	88.03	84.22	7.00	100.00	89.93	74.06
8.00		2100.00	8.00	92.03	81.81	78.44	8.00	92.71	84.12	58.71	8.00	100.00	81.81	-13.58

			Yandee				Gaebung				75A329			
			TDM	Low	Med	High	TDM	Low	Med	High	TDM	Low	Med	High
1.00		11.00	1.00				1.00				1.00			
2.00		258.00	2.00				2.00				2.00			
3.00		517.00	3.00	236.85	130.18	306.51	3.00	812.99	5.66	971.50	3.00			312.50
4.00		781.00	4.00	258.34	124.39	143.79	4.00	763.20	-48.41	1118.77	4.00			816.47
6.00		1390.00	6.00	715.21	686.56	2107.81	6.00	1474.19	748.00	2213.14	6.00	915.15	810.11	3148.64
6.00		1821.00	6.00	1413.12	######	4213.70	6.00	1762.86	1920.31	3178.83	6.00	932.13	1695.24	3048.81
7.00		2100.00	7.00	2037.83	######	4615.85	7.00	1778.84	2451.22	3330.11	7.00	932.18	1741.92	2487.93
8.00		2100.00	8.00	2323.96	######	2796.66	8.00	1694.81	2263.24	2089.62	8.00	932.18	1814.16	414.76

	Yandee	Gaebung	75A329
Yield A	1218.42	1004.86	779.93
	1315.83	1231.76	1011.43
	######	1172.82	604.30

APPENDIX G: Map of Tasmania showing geographical locations of experiments.

Elliott experiments
Cressy experiments
Ross experiments